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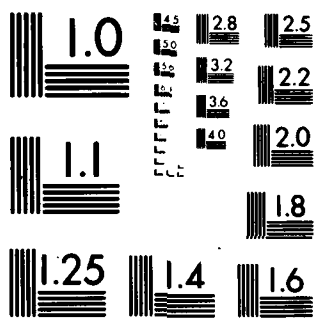

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The Pennsylvania State University

The Graduate School

Department of Architectural Engineering

Computer Applications for Air Force Construction Management

A Thesis in

Architectural Engineering

by

David Van Henrichsen

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

August 1979

DISTRIBUTION STATEMENT A
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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 79-198T ✓
2. GOVT ACCESSION NO.: AD-A091 030
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): (6) Computer Applications for Air Force Construction Management.
5. TYPE OF REPORT & PERIOD COVERED: (9) Master's Thesis,
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): (10) David Van Henrichsen
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: AFIT Student at: The Pennsylvania State University
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: (12) 131
11. CONTROLLING OFFICE NAME AND ADDRESS: AFIT/NR WPAFB OH 45433
12. REPORT DATE: (11) Aug[redacted]979
13. NUMBER OF PAGES: 121
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (14) AFIT-CI-79-198T
15. SECURITY CLASS. (of this report): UNCLASS

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

APPROVED FOR PUBLIC RELEASE AFR 190-17.

Fredric C. Lynch

FREDRIC C. LYNCH, Major, USAF
Director of Public Affairs

23 SEP 1980

18. SUPPLEMENTARY NOTES

Approved for public release: IAW AFR 190-17

Air Force Institute of Technology (ATC)
Wright-Patterson AFB, OH 45433

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Date of Signature:	Signatories:
7/23/79	Gifford H. Albright Gifford H. Albright, Professor of Architectural Engineering, Head of the Department of Architectural Engineering, Chairman of Committee, Thesis Advisor
7/20/79	Jack H. Willenbrock Jack H. Willenbrock, Associate Professor of Civil Engineering
7-20-79	Louis F. Geschwindner Louis F. Geschwindner, Assistant Professor of Architectural Engineering
7-20-79	H. Randolph Thomas H. Randolph Thomas, Assistant Professor of Civil Engineering

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ABSTRACT

The application of computers to construction management is discussed with emphasis on Air Force construction management. Three basic areas of computer knowledge are covered: computer development, computer application to private construction management, and computer application to Air Force construction management.

An overview of the development of the computer illustrates the problems and various factors present in the acceptance and application of the computer from initial discovery, through its technological advancements, to the microcomputer of the seventies. A discussion of computer applications in the construction phases includes examples from a basic construction-oriented computer program, ICES PROJECT-I.

Air Force construction management is analyzed through various levels of management organization determined by project size and complexity. Actual computer applications at these levels are analyzed on the basis of interviews, regulatory documents, and an overview of a construction management computer program utilized by the Air Force. Conclusions and recommendations are given with the purpose of enhancing the Air Force construction management program.

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LIST OF ABBREVIATIONS

A-E	Architect-Engineer
AMPRS	Automated Military Construction Progress Reporting
CM	Construction Manager
COE	Corp of Engineers (Army)
COEMIS	Corp of Engineers Management Information System
CPM	Critical Path Method
CPMT	Critical Path Method Training
ENIAC	Electronic Numerical Integrator and Calculator
ENR	Engineering News Record
ICES	Integrated Civil Engineering System
NAFAC	Naval Facilities Engineering Command
PERT	Program Evaluation and Review
PROJECT	Project Engineering Control
STS	Space Transportation System

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Professor Gifford H. Albright for his assistance and guidance in the preparation of this thesis. Special recognition is also to be given to Drs. Louis F. Geschwindner, H. Randolph Thomas, and Jack H. Willenbrock for the professional knowledge and review which resulted in this thesis.

CHAPTER I

INTRODUCTION

Construction management personnel are responsible for a multitude of integrated tasks as part of the planning, scheduling, and controlling of a construction project. Today's complex construction projects, both public and private, require highly trained and skilled managers who must use sophisticated management tools to accomplish these tasks.

One such tool, which has provided positive results in other management fields, is the computer. Although the computer has been applied successfully on a number of construction projects, many construction managers still favor traditional management methods. These methods involve manual operations which are time-consuming and subject to human error. Although efficient in the past, manual methods can no longer provide the quality of up-to-date information required on complex, large construction projects. The sheer volume of information required for these projects is overwhelming. With the aid of the computer, the construction management decision-making process can be accomplished with greater speed, efficiency, and quality, thus, saving time and money.

The computer's full potential cannot be recognized or utilized in the construction management field unless the construction manager has an understanding and knowledge of the computer's benefits and capabilities. It is crucial, therefore, that education and training

in computer applications and capabilities be provided to the construction manager in both the public and private industry. Private industry, being well ahead of the public sector in computer applications, has taken the lead in this endeavor and, perhaps, should serve as an example to the public construction managers.

For this thesis, private construction refers to construction in the commercial industry. Emphasis will be placed on public construction, which refers to construction under government administration. Particular emphasis will be placed on military construction, primarily that of the United States Air Force. The terms Air Force, Army, and Navy, as used in this thesis, refer to the military branches of the United States government.

The information and examples discussed in this thesis are the result of the writer's initial research concerning his own future assignment with the Air Force. The findings were derived throughout a period which began with a personal visitation to an Air Force construction management division in July, 1978, to the final summation of the information and the authorization to use references which was obtained in November, 1978.

Management Background

The discipline of management has undergone considerable changes in its application and definition since its initial recognition. Early management practices actually favored Webster's definition of management

as the "act or art of managing." While this may be sufficient for a common, everyday definition, management researchers and authors strongly reject the idea of strictly classifying management as an art. Several authors (1, 44, 52, 55) indicate that management is actually a combination of both science and art. In the past, the natural abilities and skills of managers have proved to be sufficient. The complexities of today's modern professional management, however, require the addition of a scientific approach.

A well-defined history of the evolutionary process has been portrayed by several authors (5, 6, 44). It appears that the evolutionary process that has produced our present day management practices was first documented in relation to the Industrial Revolution of 1750 and 1850. Prior to that period, businesses were small and industrial activity did not have significant economical value. Thus, management was not a primary concern, and the leadership provided was based on man's natural ability and skills. The emphasis on machinery and assembly line production methods during the Industrial Revolution brought about the need for increased management applications. Watt (1795), Owen (early 1800's), and Babbage (1832), made the first realistic management applications in the field of production engineering. The studies of Taylor (1880's), Ghant (1880's), and Gilbreth (1880's) added new dimensions to the definition of management. These men indicated the need for a scientific approach to management applications; at that point in time, however, managers were not ready to accept this revolutionary approach in lieu of proven natural ability and skills.

Fayol (1908) analyzed his daily executive experiences and took the scientific approach to management one step further. He categorized some basic principles of management in order to educate others. Although Fayol's concept that management principles should be taught was not accepted during his time, a number of current management textbooks present similar principles. Fayol's concept of education in management has since been reinforced, as evidenced by the later development of management theories and texts and the actual management training programs established in schools and universities. These developments have provided a foundation for today's scientific approach to management.

The importance of continuing developments in the scientific approach to management is presented in Allen's (1) study of management as a profession. Allen recognizes and emphasizes the need for an "increase in knowledge" and an "improved education of managers" as they become professionals. In discussion the requirements for "young and aspiring leaders," he states that "education is our greatest need . . . (1:88)." Thus, education is the key to the future of management as a science and as a profession.

The management evolution was based on the complex needs of expanding industries. Education and training of managers proved to be essential in this evolution. The particular field of construction management, as one of these expanding industries, required improvements in management practices in both the private and public sectors. The responsibilities of private and public construction management, the

need for improvements in management techniques, and the role of the computer as a development of the scientific approach to management will be discussed in the following sections.

Construction Management

The construction management process can generally be divided into the phases of organizing, planning, scheduling, and controlling. Organizing and planning are the identification and orderly arrangement of the requirements of the construction process, such as the work activities and the resources of manpower, equipment, and material. Scheduling establishes a time framework for these requirements. Their interrelationships and interdependencies must be evaluated and considered in order to create a precise and workable schedule. Controlling a project occurs throughout the construction phase. This is the process of directing the construction effort to insure that the schedule and budgetary constraints are satisfied.

The integration, coordination, and interfacing of the total environment of the construction process which sometimes can begin as early as the initial design phase, requires an extremely knowledgeable and capable manager. He must be able to combine his skills in the art and science of managing with his thorough understanding of the concepts and requirements of the construction process. The construction industry has advanced in technology, volume, and complexity to the point where a construction manager must make use of every management concept and tool available to him in order to make cost-effective and timely decisions.

Are Improvements in Construction Management Necessary?

Traditionally, construction management, as in other types of management, has been accomplished through natural skills and abilities. The earlier scientific management approaches applied to the manufacturing industry were not designed for the construction industry (44). Routine operations and the assembly-line procedures of the "industrial trades" could not be readily applied to the everchanging conditions and requirements of a construction project. Management personnel, supervisors, foremen, and workmen varied with each project. Methods of construction and use of materials also changed with each project's location, functional design, economic influence, and other criteria. The construction industry itself was subject to fluctuations in business volume. Under these circumstances and operating conditions, construction management definitely required a change in its management approach. Improvements had to be made to continue to advance the construction industry.

In addition to these same conditions, today's construction industry must operate with an ever increasing "tight-money" policy and a continuing growth in complexity due to new technology and construction developments. With the construction industry, both foreign and domestic, being a major element in our nation's economy (9, 52), construction management can ill afford not to continue to make improvements in its management practices and techniques.

Improvements and Growth in Construction Management.

The total process of constructing a building has traditionally been accomplished in four separate and sequential periods of time (22). First the decision to build is made, then the design is developed. This is followed by a bidding period to obtain a contractor before the final period of the physical construction is accomplished. Construction management has traditionally been active in only this final construction period.

A process called "fast-tracking" or "phase-building," which has recently been developed, permits these separate periods to be overlapped, thus, resulting in significant savings of time and money if properly administered. This process requires an integration of these periods by one individual, often called a "construction manager," who can advise and make recommendations concerning all of the construction aspects as early as the initial design phase. Essentially, this "construction manager" coordinates the activities of several contractors or subcontractors who do not know or care about the needs of others.

The actual term, construction manager (CM), was not applied to this position until government officials decided that an individual manager was required to advise during the design and to organize and manage the many separate contractors required by regulation on government construction projects (47). This CM usually has no contractual agreement with the separate contractors and receives a separate fee for his work.

The construction industry today still successfully employs the traditional methods of construction on numerous projects, however, the use of the methods of fast-tracking and the CM approach have significantly increased in recent years. The type of project and the choice of the owner and the architect determine whether or not to incorporate these newer methods in their construction projects.

The advantages and disadvantages, of each method, although not intended to be included in this thesis, must be separately applied to each construction situation to determine the best applicable construction method to be used. The complexity of a project alone can determine a need for a CM function. Fast-tracking is more dependent on timeliness and cost effectiveness.

In private construction, the CM function has been provided by separate CM organizations or as part of the services offered by a number of general contractors. Its importance is indicated by its increased application. In 1976, one-fifth of the ENR Top 400 construction companies provided this specific service for their clients (25). In 1977, the figure increases as one-fourth of the Top 400 construction companies were involved by providing specific CM services (26). These figures do not provide information about the many firms not in the Top 400 who also provided these services, or the CM services provided by companies which do not appear in a separate billing category. It is apparent that the construction management field is developing into a more technical and professional field requiring highly qualified and knowledgeable managers.

Clough (8) suggests that a new generation of scientific construction management concepts has emerged and is being applied by the professional construction manager. This approach treats the entire construction process as a unified system of integrated actions. A list of the four functions involved in this comprehensive project management system are given (8:6):

1. The detailed planning of the construction operations,
2. Time scheduling of these operations,
3. Control of time and costs through project monitoring and periodic correction and readjustment of the construction plan, and
4. Administration of the contract.

This system, employed by most construction companies in some form, is usually based on a network model of the many activities of a construction project. A detailed analysis and understanding of the intricacies of a project are gained by the project manager in the formation of this network model. Costs and time control are achieved through actual progress monitoring and a comparative analysis with the model. The forms and reports developed in the system, when considered with the overall project requirements, provide the essential information for construction management decision-making.

The actual computations and manipulation of the information required for large, complicated projects is very tedious, time-consuming, and costly. Construction companies and managers have, therefore, been acquiring and employing new and sophisticated management tools. One of these, the computer, has had major advances in technology, and has received wide-spread application as a construction

management tool. The role of the computer in construction management will be traced in this chapter after another aspect of construction management is reviewed, that type of construction management found on military projects.

Military Construction Management

The Army, Navy, and Air Force branches of the military conduct extensive construction programs annually (35, 49, 50) which also require highly trained and knowledgeable construction managers. These military construction programs place the primary responsibility of insuring the satisfactory design, construction, and acceptance of their construction projects in the hands of the military construction engineers and managers.

The Army Corps of Engineers (COE), an agency of the Department of the Army, is responsible for the largest volume of the military construction and also has a civil governmental construction commitment. In the military construction program, its primary function is to serve as the contracting agent for the construction of its own projects, large projects of the Air Force, and some selected Navy projects. The COE's civil responsibilities include government construction programs such as the federal water resources development program and the National Aeronautics and Space Administration's space programs.

The Naval Facilities Engineering Command (NAFAC) is the Navy's counterpart of the Army's COE. As such, it acts as the contracting

agent for its construction programs and also for designated Air Force projects. A major part of the Navy's construction programs has been in its housing projects which have emphasized "turnkey" construction concepts. Other Navy projects have included hospital construction, shipyard modernization, aircraft rework facilities, public works projects, Marine construction projects, and some Air Force administrative building complexes and housing developments.

The Air Force construction program has for quite some time been comparable to the Navy's program in terms of dollar volume, but has recently undertaken some larger, multi-million dollar projects such as the addition and renovation of the Air Force's Wilford Hall Medical Center and the development and construction of the Space Transportation System (STS) facilities of the space and missile system program (12). The Air Force traditionally functions as the contracting agent on only a limited number of its own projects such as family housing construction, maintenance and repair projects, and construction of recreation facilities. Close coordination, surveillance, and control must still be established by the Air Force construction managers for all its construction projects since actual project management is the responsibility of the particular branch of the service, which will eventually operate the facility.

It can be concluded that the military construction manager must be capable construction manager, able to utilize the basic principles of management on a variety of projects. Since he is usually an engineer as well as a manager, he must have a sound engineering

background, must be adaptable and open-minded, and must be skilled in management techniques (43).

Professional training and education are essential, but the mere application of the knowledge and skills which he acquires are not always sufficient to achieve the most efficient and effective results. The military construction manager, just as his counterpart in civilian or private construction, must learn to apply the tools of management available to him. These tools include the application of the computer to construction management procedures.

Role of the Computer

The necessity for rapid computations and timely information for management decision-making has created the need for sophisticated and scientific management tools. The computer, with its high speed storage, calculation, and recall capabilities and flexibilities, is the ideal management tool for providing the needed coordination and dissemination of the information which is required to allow efficient and effective decision-making.

Management must be kept accurately informed in all areas of its responsibility without being swamped with excessive and impertinent data. Besides the speed and accuracy required, the computer can sort and manipulate information to bring to management's attention only those critical areas required. The computer can be programmed to determine what is critical and to highlight this information or

summarize it in a concise form. Thus, the computer enables the application of the concept of "management-by-exception," in which only items requiring attention are reported for management action. The manual deciphering and sifting of unimportant information is therefore eliminated and a savings of time and money is realized.

The computer is now being applied to management in almost every industry. As technological breakthroughs improve the computer's capabilities and decrease its expense, more companies will continue to acquire and use computer services.

It is felt that the computer has great potential as a management tool for the construction manager in the construction industry. To benefit from this potential, however, the construction manager must first understand the computer, although he does not have to become a computer programmer or an expert on computers. He must, however, be knowledgeable about the benefits and capabilities of the computer. With this knowledge he can then determine if the computer could provide benefits to his specific work. Once this is determined, he can take the necessary steps to utilize the computer and to obtain these benefits (52, 54).

It is suggested that the real potential of the computer lies in its ability to provide the communication link for the entire construction process (24). The construction manager requires information concerning the total project to make accurate decisions affecting future activities and conditions of the project. He may have to coordinate resources with other construction projects in which his firm is

involved. The computer can store and selectively reproduce the desired information with greater speed.

The computer is also highly beneficial in the individual construction phases of planning, scheduling, and controlling. The many calculations, evaluations, sorting of data, and other information-handling requirements can be extremely tedious, redundant, expensive, and subject to error if the traditional manual methods are used. An analysis of a typical computer program in Chapter III will provide an example of the possible applications of computers in construction management.

Objectives

It is felt by this writer that today's Air Force construction managers are not using the computer to its fullest capability. There appear to be several factors which are the basis of this failure, resulting in a loss of greater efficiency and thus savings.

The purpose of this thesis is to provide an introductory document that presents an overview of the benefits and evolution of the computer and to examine various aspects of computer utilization that are relevant to the Air Force construction management field. The knowledge gained and the conclusions reached can then aid the Air Force construction manager in achieving greater utilization of the computer in the accomplishment of his construction management duties.

The specific objectives which will accomplish this purpose are:

1. Provide a general background and development of the computer,

2. Explain the application of the computer in pre-construction and post-construction phases which can aid the construction manager,

3. Indicate how computer programs can be directly applied to aid construction management in the actual construction phases of planning, scheduling, and controlling a construction project,

4. Discuss the duties and responsibilities of the Air Force construction manager in the various organizational levels of a construction project and analyze examples of computer applications at these levels,

5. Provide an overview of a computer program currently being used by the Air Force,

6. Draw conclusions concerning the further application of computers as a management tool on construction projects.

7. Make recommendations as to how the Air Force construction manager can apply his knowledge of computer capabilities to aid in his construction management duties, and

8. Make recommendations as to steps the Air Force can take to receive more benefits and efficiency from computers and greater utilization of the construction managers in its construction program.

Scope and Limitations

The scope of this thesis is primarily concerned with providing the Air Force construction manager with a starting point from which he can begin to learn about computer capabilities and benefits and to apply them to the various stages of a construction project. Direction will also be provided to the Air Force to aid in this accomplishment.

The study provides a brief history of the computer's development and its introductory use in construction management, examines the needs

and benefits of training and education with computer programs, and analyzes a basic computer program as applied to a typical construction project. The Air Force construction management field is analyzed with regard to the duties and responsibilities of the Air Force construction manager in its various organizational levels, the impact of the present computer situation at these levels, and an overview of a computer program being utilized on Air Force construction projects.

The scope of this thesis is not intended to be such that the Air Force construction manager will become an expert in developing or using computer programs, but should provide him the background to adequately and knowledgeably assess his own situation to determine if he could possibly benefit from computer applications. In addition, computer programs will not be analyzed with respect to their cost or availability, thus, no one program will be recommended in favor of another.

CHAPTER II

COMPUTER DEVELOPMENT

This chapter provides an overview of the evolution of the computer as well as an indication of its changing role in management. This changing role has been due in part to the reluctance of management in general to accept and use computers. This reluctance by management has also been reflected in the construction industry. It is felt by the writer that if Air Force construction managers are made aware of the evolution of the computer and the problems of acceptance which have been encountered, similar problems could be avoided in Air Force construction management areas.

Evolution of the Computer

The early predecessors of the computer were innovations and inventions that were in response to a need for improved methods of counting and calculating. The computer itself was merely an extension of these earlier ideas and concepts. Its development to its present form has been presented by several authors (23, 28, 32, 40).

It appears that the first mechanical aid to calculation emerged during early Greek and Roman times. The Babylonians are credited with the development of a primitive abacus; present form of the abacus is credited to the Chinese. Its use slowly began to disappear in Europe in the fifteenth century. It is still used today, however, in some Eastern Asian countries.

In 1614, John Napier of Scotland reduced the labor of long multiplication and division with his invention of logarithms. This was followed in 1632 by Oughtred's invention of a primitive slide rule. Today's version of the slide rule was not developed until 1850 by Mannheim.

Pascal originated the concept of addition and subtraction by mechanical means in 1642. His complex set of toothed wheels included a carrying mechanism. About twenty years later, Morland produced a similar adding machine and a multiplying calculator. In 1694, Leibniz developed the first machine to multiply, divide, and subtract directly without resorting to complement arithmetic. Other machines followed through the eighteenth century. None of these earlier calculating devices were considered reliable, thus, they did not become popular. Their principles, however, were used in later concepts and inventions.

In 1820, the first successful, manually operated calculator went into commercial production. The addition of a motor in 1920, resulted in the first electrical calculators.

Charles Babbage is considered the "father" of the computer. In 1883, he developed the plans for an "Analytical Engine" that contained all of the essential features of a modern computer. His plans were never completed because the necessary materials and methods of construction were not available during his lifetime.

The next seventy years witnessed the emergence of several forms of calculating machines and semi-automatic calculators. The development of the first successful electronic computer was a result of

concentrated and coordinated research efforts by teams of scientists and engineers at two separate locations.

These first fully electronic computers were developed independently at the University of Pennsylvania and at the German Aircraft Research Institute. Each was developed as a result of an intensified research effort brought upon by military necessity during the Second World War. The American version was the Electronic Numerical Integrator and Calculator (ENIAC). Despite its initial failings, it proved that automatic computation was feasible. By 1950, the computer was on the commercial market.

The first commercially-marketed computers, (i.e.: the first generation computer), incorporated vacuum tubes, were relatively slow, had low reliability, and had a limited memory capacity. Transistors replaced the vacuum tubes in 1959, permitting a reduction in both size and costs. These second generation computers had an increase in reliability and speed with a greater memory capacity. A further increase in benefits and more widespread application were achieved with the advent of the third generation's solid state circuits in 1965. Other third generation advancements included remote terminals, time sharing, and software improvements. Since 1971, the fourth generation has provided large-scale computer networks, mini-computers, microcomputers and microprogramming. The capacity, speed, and reliability have increased quite noticeably while cost and size have greatly decreased. It is noted by Mitchell (40) that numerous inexpensive, compact, and powerful microcomputers are now available.

The future of computers is expected to include even greater memory capabilities, reductions in size and cost, and a further increase in speed. It has been stated that "every 4½ years, the cost of computer equipment is cut in half, and its power increases 10 times (11:101)." While the costs of hardware are decreasing because of the technological advancements in production methods, the costs of software programs are expected to increase. The professional skill required to manually write software programs continues to rise.

The evolution of the respective generation of computers has resulted from years of research and technological study. Since the marketing of the first computer, its application has been felt in nearly every aspect of industry. During this period, the field of management has demonstrated various reactions and some opposition to the use of computers. This topic is discussed in the following section.

Changing Role in Management

The computer made its initial entry into the business profession in the early fifties. The first major computer applications were for routine office work and clerical functions. Because of its speed, the computer could digest, rearrange, and summarize large volumes of information rapidly. Its ability to perform large amounts of repetitive clerical operations at a rate far exceeding those performed manually, established the computer as a vital administrative tool.

In many instances, the growth of enterprises and the complexity of information that accompanied this growth, had exceeded management's

ability to provide manual control. The computer emerged as the management tool that processed this abundance of information. Through efficient and accurate programming, the computer became the communication means to interpret, analyze, transmit, and store data.

The speed with which the computer could process complex information provided management with up-to-date reports on items effecting the immediate situation. These timely and up-to-date reports enabled management to base its decisions on knowledge of the present situation rather than on past experience and history. Consequently, with the addition of all relevant facts, the accuracy and quality of management decisions were improved.

It is concluded that from the beginning computers had the capability of aiding the manager in his responsibilities. The benefits shown by some of the first computer applications indicated only a few of the possibilities and a small fraction of the potential of the computer. Yet, computer application did not expand without failures and skepticism. The following sections will discuss some of the reasons for the failures and skepticism, and the steps that have been taken to alleviate these situations in the management field.

Problems in Acceptance and Application

The advent of the usage of the computer in management was accompanied by mixed emotions and attitudes (31, 32, 39, 55). The skepticism of something new and untried deterred many managers. The application of computers in industry had replaced many workers. This

"unemployment scare" further strengthened the resistance to "computerize." Another problem was the zealous, power-hungry manager who saw a chance to build his own area of power around the computer. Others joined this "bandwagon" to computerize in order to keep up with the times and recklessly converted their firms to a supposedly automated management system. Only a few of the early changeovers to computers were successful, most were not.

Top Management Failings

Some early failures of computerization were also related to top management's lack of computer knowledge and the fact that changes in the role of decision-making caused by new technological advances, such as the computer, occurred too rapidly for the senior managers. Their preference to stay with proven traditional manual techniques often slowed the decision to computerize. Without the commitment and backing from top management, a successful change to computers was often stymied.

It should be noted that the original application of the computer was for simple calculations related to financial and routine clerical work (31, 32, 55). This work occurred at the "bottom" of any management organization and therefore, did not receive the required attention which was needed to insure its success. The failures that occurred resulted in computer "jokes" and "stores" which only reinforced the resistance against the computer's use. Under these circumstances, the real capabilities of the computer could never be fully realized.

Improper Training and Utilization

Oftentimes when a company did acquire a computer system for its use, it failed to provide the necessary training and education to the employees who used the computer output. It is indicated that much of the output was redundant, changes in the system were made without the user's knowledge, and some information was inaccurate (39). This often caused users to discount accurate information. Thus, because of the lack of proper training and orientation on the part of the user and the information supplier, a self-defeating cycle evolved. It was concluded that without management's involvement in the computerization of a company, the computer's capabilities were only slowly utilized and accepted.

Computerization Process Failings

The computerization process itself has also been the primary reason that some firms have been reluctant to accept computers. The first problem is that, as indicated by early economic failures, computerization cannot be achieved overnight. Tomeski (55) points out many of the pitfalls that can and have occurred to numerous firms.

The initial high praise given the computer was a factor which caused firms to completely computerize without first performing a feasibility study or making the proper plans for operation. The salesmanship of computer companies glamorized the benefits of the computer and deemphasized the "small" disadvantages such as software procurement difficulties, building renovation requirements to accommodate

the computers, and air conditioning system requirements to keep the bulky, heat-producing computers from overloading. Thus, an additional financial burden was added to the basic cost of computer equipment.

The initial high costs of computer hardware and software added to the resistance to computerize. Optimistic payback periods were also not achieved due to poorly planned changeovers to computers.

In many cases, the projected time required to become operational was underestimated. Tomeski (55) notes that in the early sixties computer delivery time took twelve to twenty-four months, software delivery was many times delayed, and required training took additional time away from production. Consequently, large-scale applications were oftentimes not achieved for years.

Construction Related Problems

The construction industry also experienced many of the initial computer problems. The original application of the computer was not oriented to construction operations, and changes in application were not of major concern to construction managers. It appears that the development of the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) methods of project scheduling in the late 1950's was responsible for the first real application of the computer to construction management in the early 1960's.

The original computer versions of CPM and PERT, however, contained many programming inadequacies. At the same time almost every construction magazine was praising CPM as "necessary for survival" and necessary

for a "successful contractor (21)." This overrating of their initial applications encouraged much of the premature computerization in the early 1960's.

The initial reluctance to utilize computers as indicated above, resulted from various circumstances and factors. Since the first application of the computer, however, there have been numerous innovations and advancements through research efforts that have aided the computer to become more widely utilized and accepted. The areas in management and the construction industry which were significantly affected by these aids are discussed below.

Aids to Acceptance and Application

Although the acceptance of the computer has not been totally achieved, there has been a considerable increase in its application in the management field. One of the major factors contributing to increased computer acceptance is the decreased cost of computer operations.

Service Bureaus and Time Sharing

The original high cost of computer hardware proved economically unfeasible for many companies. The advent of service bureaus and time sharing helped to eliminate this initial high cost. Firms not requiring continual use of a computer were able to reduce expenses by purchasing or renting only the remote terminals that were linked to the larger processing unit. The firms, therefore, had access to the computer and

were charged only for the time that it was used. Although time sharing was originally offered by computer manufacturers through service bureaus, its concept was applied by companies endeavoring to utilize the full capacity of their large computers. By renting computer time to other companies, their return on the computer investment was increased. The cost-saving alternative of several businesses using one computer resulted in a more viable and accessible tool for management purposes.

Software Centers

Another aspect considered in alleviating management's reluctance to use computers was the accessibility of software programs. Software programs are the systems that allow the computer to function. Hemes (33) further explains this with his division of software into two sets of systems: programming systems and operating systems. The programming systems consist of the languages for writing programs and a translator which encodes the programs to the machine language. The operating systems monitor and control other programs and take charge of computer operations. Therefore, anything in a computer system that is not hardware (the computer equipment itself) is considered to be software.

Highly skilled personnel are necessary to write accurate and effective programs. The additional economic burden of retaining skilled personnel to write these programs for each computer user compounded management's reluctance to accept computers. A means of alleviating the high cost of software programs was achieved through the advent of software sharing centers.

Since many of the same or similar programs were required by management in different organizations, software centers were established to both maintain general use programs as well as to furnish specialized programs. Some computer manufacturers offer this service and maintain extensive program libraries as part of their sales packages. These programs may also be purchased separately. Specially formed computer consultant companies also include software programs as part of their computer services. Other software sharing is possible through universities and through time-sharing operations formed by computer users. Thus, software programs have become more accessible.

Minicomputers

Although technology advancements in computers had greatly decreased the initial high costs, many small firms could still not afford the expense of owning computers or renting computer services. Their requirements for computerization were at a much smaller capacity level. The introduction of the minicomputer in the late 1960's filled this requirement.

A turnkey minicomputer package was designed to fill the gap between accounting machines and medium-scale computer systems. During the yearly period prior to October 1978, there was an 800% increase in the number of suppliers of small business computers (51). This new approach gives management greater insight into all aspects of business, especially project management, inventory control and accounting.

Microcomputers

The microcomputer is the latest addition to the computer industry (37). It has less input/output capacity than the larger computers, but greater processor speeds. It was developed in the early 1970's, is based on the computer chip, and is being added to the computer supplier's equipment line.

Just as the minicomputer fulfilled the smaller needs of the computer industry, the microcomputer is finding its place in the computer world. Together they are fulfilling the users' demand for the growing conversion to computers. Their continual growth in the future is expected as indicated by the fact that many service bureaus are installing these systems at customer sites in order to remain in competition.

Education and Training

For computers to be accepted and utilized by management, an upgrading in the education and training of managers was found to be essential. With the advent of software centers and consultants, personnel highly trained in computer programming and operations were made readily available to aid firms in the changeover to computers. Universities began to increase the quality and quantity of computer courses available as research continued to expand. Program languages and input criteria were simplified to a level easily understood by the manager.

Computers in Education and Training

Additional education and training problems in construction management are discussed by Paulson (42) and Halpin (30). It is pointed out that students today do not have the same opportunities as earlier managers had in developing "hands-on" management experience. This experience was achieved through the years as field laborers and supervisors were promoted in the organizational structure to higher management positions. With the increased union entry restrictions and changing managerial and professional patterns, this source of management personnel has declined. Few new managers of today possess the experience that is essential in eliminating the high cost of errors in decision-making. Teaching tools such as computer simulation and computer games, although not new ideas (30), are being utilized to reduce the education gap caused by this lack of available "hands-on" experience and also the failure of educational courses to adequately provide up-to-date information concerning large-scale construction operations.

One such teaching tool, developed for CPM classes by Popescu (45) at the University of Texas at Austin is in the form of a computer package called Critical Path Method Training (CPMT). CPMT enables the student to plan and schedule a construction project on a limited scale. This actually enables the student to get a better understanding of the detail involved in a project. Furthermore, it allows him to make inputs and changes as time "progresses" and to see the results of his decisions. With almost immediate results of his inputs, an

improved learning environment is created. Giving a student the opportunity to "control" a construction project enables the student to get practical experience without the involvement of costly errors.

Another similar construction management game developed by the Civil Engineering Systems Laboratory at the University of Illinois is CONSTRUCTO (30). This offers the student the opportunity to become familiar with a simulated construction project. The student "player" is placed in charge of this simulated project. He makes construction management decisions on the requirements to complete the project. The computer simulates environmental conditions such as weather, labor, and economics over a designated period of time. The student then analyzes the progress reports and expenditures and makes necessary changes and decisions to keep progress and cost on schedule. The objective of the game is to complete the project within the time and cost limitations.

A construction project's success is directly dependent on the construction manager's skill, judgement, intuition, and experience in managing a project. Computerized management games can aid in obtaining these characteristics as well as in providing a better understanding of computer application.

Summary and Conclusions

It is felt that a better understanding of the computer's development, the difficulties encountered in its acceptance, and some achievements and improvements available to counter these difficulties will

provide the Air Force construction manager a better perspective and background to aid in his own recognition and acceptance of the computer.

This chapter traced the development of the computer from its initial concepts through its four generations to the microcomputer. When first introduced as a management tool, its implementation and application were not readily accepted, but were met with skepticism, high cost factors, and improper management in the computerization process. The construction industry experienced these same factors along with an initial overrating of its use with the new scheduling methods of CPM and PERT. Technological achievements along with the creation of service bureaus, software centers, and time-sharing have since significantly decreased the cost of computer usage. Training and education improvements further aided the acceptance of the computer and also provided construction management with computerized training aids to gain valuable construction "experience", not otherwise available, through simulation and games.

With a greater awareness of these problems and developments, the Air Force construction manager will be more prepared to implement computers in the construction management field. Attention can now be directed to computer applications in that field.

CHAPTER III

COMPUTER APPLICATIONS

Computer applications to aid in construction management, especially in the private sector, have been continually increasing as computer technology decreases computer cost and more construction firms are realizing the benefits and advantages that computers offer. Time and cost savings through computer applications can be realized from the initial concept phase of a construction project through to the completion and evaluation of the project. The Air Force construction manager should understand and be aware of these computer applications and their benefits in order to utilize the computer to its maximum capabilities.

This chapter discusses applications of the computer for a construction project in the pre-construction phase, the construction phase, and the post-construction phase. The pre-construction and post-construction phase. The pre-construction and post-construction phases are included only to indicate that the computer can be and has been used in areas other than the construction phase. To achieve maximum benefit from the computer's use, the information from one phase is essential and interrelated to the success of the following phases. Thus, the construction manager benefits both directly and indirectly from the use of the computer.

The application of the computer in the planning, scheduling, and controlling aspects of a construction project is demonstrated through

a basic computer program, ICES PROJECT-I, which typifies those used by many construction companies today. This program was selected because it is easy to understand, it is applicable to a practical construction project, and it was available for actual computer demonstration.

There are many variations of software packages (i.e.: computer programs) used by construction companies, but the basic procedures involved and schedules produced are similar. It is beyond the scope of this thesis to provide an in-depth coverage of these other software packages. A partial listing of some of the many available computer software centers that provide these computer packages is listed in Appendix B for the interested reader. Some of the options available with other programs will be pointed out in this chapter. No particular program will be selected or rated over others since each construction company may incorporate variations to satisfy their particular needs and methods of operation.

Pre-Construction Phase

The use of the computer in the pre-construction phase of the construction process has been greatly expanded in recent years. The construction manager is both directly and indirectly affected by these applications. The use of the computer in areas such as design, quantity take-off, cost estimating, specification development, and contract documents provide greater accuracy, speed, and standardization, and ultimately affect the construction process itself.

The extent of the involvement of a construction manager in these areas is discussed by several authors (8, 9, 10, 64). Contract agreements can include the construction manager's services in the early design stages (the aspect of CM previously mentioned), or only in the construction process itself. A discussion of these contractual arrangements and services is not included in this study.

Quantity Take-offs

Initial construction planning involves quantity take-offs and their associated cost estimates. The manual methods of calculating areas, measuring lengths, and counting items can be greatly expedited by using quantity calculators (10). Measurements are taken directly from the drawings by tracing and counting with an electronic stylus or digitizer automatically calculate quantities. This information is then transferred to a computer which processes it with a data base that contains standard specifications and cost data, and computes a cost estimate.

Cost Estimates

Cost estimates are also considered part of the pre-construction phase. The construction project must be designed to remain within the owner's financial limitations which can be accomplished if it is known in advance what the project will cost.

A rational cost estimate must be developed by the architect, the engineer, or both before any substantial amount of design has taken place. The increased speed of calculation by computers allow cost

comparisons to be made using different choices of construction methods, materials, and equipment. Although various computer equipment and data bases are used by different design agencies, increased efficiency and savings are the overall result.

Design Selection and Optimization

To optimize a building's design, a data base containing standard building descriptions for specified spaces and areas and a data base of cost information are required. The building's design information is placed on the computer. The spaces and areas as selected are assigned the corresponding cost data by the computer and an estimated cost is developed. The building design can be varied on subsequent computer runs to obtain new estimates. Computer programs have also been written that minimize costs and maximize areas automatically. This occurs through the automatic transformation of the given requirements from one pattern or arrangement to another while comparing the results and then listing the outcome in a ranking order.

Engineering Calculations

The completed construction design requires many calculations that are of a routine and repetitious nature. Computer programs have been written which perform calculations in the structural, mechanical, electrical, and civil engineering aspects of design. A survey completed by the Department of Architectural Engineering at The Pennsylvania State University lists hundreds of programs used by architectural engineering and design firms throughout the United States (20).

Much time is saved with rapid computer calculations of problems such as heat gain-loss in mechanical design, room illumination in electrical design.

Specifications

The preparation of specifications is another time consuming, yet very important part of the pre-construction phase. Specifications are the criteria that determine the construction concepts and materials required to obtain the desired quality and durability of the project. To computerize specifications, a data base is again essential.

A library of "standard" architectural and engineering specifications must first be developed and stored in the computer's memory system. Designers can then recall specifications, omit portions of them, or add new specifications and have copies printed for distribution with the contract drawings. Neglecting human oversight, the results are concise and accurate specifications produced in a minimum time.

Contract Documents

Contract documents can be stored and printed in much the same manner as specifications. This results in standardization of format and a savings in time and typing. Although the documents will be clerically error-free, the accuracy of the contents still depends on the competence and thoroughness of the architect-engineer.

Computerized Packages

Many computer companies are offering complete computerized packages for the architect-engineer (A-E) office. With the advent of

the minicomputer, interactive computer-aided drafting and design have become accessible to the A-E firms (18, 34, 62). From a central "working station", the engineer-designer-draftsman has access to the computer hardware required to aid him in the complete process of conception to the actual preparation of the documents. The equipment includes digitizers, plotters, keyboards, the central processing unit, and a visual screen. The preliminary sketch or drawing of a design can be placed on the digitizer. The user can manipulate the computer to instantly display the design in two or three dimensions. Zooming, rotating, erasing, tracing, enlarging, and printing are operations that are available through simple keyboard commands and through a hand-held stylus pen. Drawings can be finalized in a few hours through computer graphics, compared to days required by manual drafting. Changes can be instantaneously made to all drawings through a single input.

An additional benefit is achieved because of improved communications in construction management. Through telephone networks and micro-wave networks, a remote video communication of the design and drawings is possible. Changes and inputs which are instantly reflected can provide accurate up-to-date management information. Problems in the field on design-construct projects can be transmitted directly to the designer's office for evaluation and correction.

It is concluded that the computer is a vital tool during the initial design and preparation phases of a construction project. The construction manager's further application of the computer in the planning, scheduling, and controlling of the construction phase is demonstrated in the following section.

Construction Phase

The construction phase begins with the initial planning and scheduling of the work activities and the cost budget on a project. The controlling phase follows to insure that the schedule and cost projections are followed with a minimum of variation. These phases can be greatly expedited by the application of the computer. It appears that most contractors or large, complex, construction projects utilize the computer to some degree, even if only to plan the initial construction schedule.

The basis of computerized construction schedules is a network of interrelated and interdependent work "activities" that form the chain of events required to construct a project. The longest single time path from project start to project finish is the critical path. The critical path method (CPM) is the process of calculating the critical path which determines the time required for the construction process.

The calculations required in determining the critical path basically involve addition and subtraction, but when these operations total several thousand for even a small project, the tasks become very tedious, time-consuming and error prone. The additional manipulation and sorting of the volumes of information that a computer can provide, make it an excellent management tool on a construction project.

Planning and Scheduling

To utilize a construction management computer program, the construction manager must possess a basic knowledge of CPM scheduling and

network diagramming techniques, and then be able to incorporate this with his knowledge and ability in construction management operations. Although he must understand the computer program's input/output commands, he is not, however, required to possess an in-depth knowledge of computer programming details or of computer internal operations. With a knowledge of these commands, he will be capable of using the computer to store, compute, select, and display the information of his project network. It should be pointed out that the computer does not plan the project. It is a management tool to aid the construction manager in planning and controlling the project by providing more information in a visual output form for a better understanding of problem areas.

Initial Planning. The initial project plan is very critical to the success of a project's timely and cost-efficient completion. As discussed by Allen (1), planning is the basis for successful management action. It is also the most difficult and time-consuming part of a project. Through the repetitious process involved in deriving a satisfactory schedule, the manager becomes thoroughly familiar with each activity. This is one of the benefits of developing a CPM schedule. Many decisions must be made in this planning process such as selecting the methods of construction, sequence of activities, and equipment and manpower resource to be utilized.

The initial project activity network is entered into the computer in any order through "store" commands. The number of activities

permitted is basically dependent on the capacity of the computer hardware. Activities can usually be added, deleted, or modified as the schedule is improved and changed.

Most construction planning schedules will list each activity and its duration, calculated early start, late start, early finish, late finish, free float, and total float. The construction manager can utilize this information to make changes and modifications in order to create a more efficient schedule.

Initial planning reviews may indicate that time constraints such as completion dates and milestone time requirements can cause scheduling problems. If these constraints cannot be changed sufficiently to permit a workable schedule, other time reduction methods such as "time compression" or "time-cost trade-offs" are possible. After each set of changes are made in the schedule, another computer run is necessary to recalculate the schedule and critical path. With each schedule revision, the construction manager gains additional knowledge about his project that will aid him throughout the construction process.

Manual calculation of each revised schedule is a very tedious and time-consuming process which is also subject to error. New start, finish, and float times for each activity are required to determine if the critical path has changed.

Resource Scheduling. A primary factor in planning a construction schedule is in the assignment of the basic resources of manpower, equipment, and materials to the activities. This assignment requires the construction manager's experience and judgement, combined with the

availability of these resources. In addition, resource costs can be projected to provide data for a cash flow analysis which is essential for fund scheduling purposes. The availability of funds must be coordinated to coincide with the requirement for resource financing.

The construction manager's purpose in resource scheduling is to keep work production at an efficient and steady rate. Since this requires coordination with the field superintendent and supervisors during actual construction, the construction manager should request their assistance in developing the construction schedule.

The initial determination of the resource requirements for each activity is only a beginning step in resource planning. Numerous tabulations and schedules are required for analysis before the final schedule is derived. These can be manually calculated and portrayed on charts and graphs, but the scheduling manipulation and presentations required to adequately accumulate this information for planning purposes can be very time-consuming and inefficient. The computer can be a valuable aid in resource planning.

Computer programs are available that provide resource leveling where demands exceed supplies by automatically rescheduling the activities and providing the construction manager with many alternative schedules for evaluation. Some programs will consider all affected resources simultaneously while others only have the capacity to consider one resource category at a time. These automatic programs result in additional cost and less involvement by the construction manager, but at times are a necessity.

The computer program utilized and selected by a construction company may have several options or only a few. The objective of planning and scheduling is to obtain an accurate, workable, and efficient schedule based on the resources and information available. The computer offers the speed, flexibility, and accuracy to perform the many calculations and manipulations of data necessary to provide this schedule.

Expediting. When a project falls behind schedule, expediting the remainder of the activities is a scheduling procedure used to bring the project back on schedule with a minimum cost increase. This is a "time-cost trade-off" in which the construction manager must determine which activities on the critical path will have the least cost increase with a decrease in their scheduled duration period. The total additional costs will be determined by the extent of the expediting required and the sequence in which the activities are expedited.

An activity can be (although not always required) expedited only to a maximum "crash point" which is determined by the physical limitations of the activity (i.e.: available manpower or machinery, shifts per day, working space, etc). Those activities on the critical path with the lowest daily cost increases are usually expedited first.

After each process of expediting, a new schedule is required to determine if the critical path has changed, since this could change the sequence of the expediting process.

Computer programs that include the capability to automatically "expedite" or "crash" a project network are available in various levels

or stages of automation. These levels permit expediting to be accomplished with varying degrees of construction manager input. As with resource scheduling, disadvantage of the increased automation is that the construction manager does not gain the intimate knowledge of the construction schedule since he does not work with it on a repetitive and detailed basis. Increased automation also requires a larger computer, which could mean additional costs above any cost savings attained by its use.

Controlling

Controlling a construction project with the aid of a computer involves updating the network schedule as the progress is completed and changes are required. The updated schedule then becomes the primary schedule to be used in making management decisions until subsequent progress requires the schedule to be updated again. This cycle continues throughout the work progress. As has been pointed out, the advantage of computer applications in controlling is the rapid and accurate updating of the information required to compute the construction schedule (2, 38).

The construction schedule, as planned in the previous section, should be accurate and free of conflicts. Schedule changes, however, are inevitable since construction is an ever-changing and variable process that is easily affected by such things as weather, labor strikes, procurement delays, inaccurate estimates, and equipment breakdowns. The construction manager's responsibility is to insure that these changes have a minimum effect on the construction process. Clough (8)

lists four actions to aid in this process:

1. Report and record job progress,
2. Compare work actually accomplished with that planned,
3. Take appropriate action to correct schedule slippages, and
4. Update schedule of work yet to be done.

Computer programs provide a management tool to aid the construction manager in accomplishing these actions. The following section provides a discussion and demonstration of how a basic computer program, Integrated Civil Engineering Systems (ICES) PROJECT-I (19), can be utilized as a management tool in the planning, scheduling, and controlling of a construction project.

ICES PROJECT-I

ICES PROJECT-I (for PROJect Engineering ConTrol) is a computer program developed between 1965 and 1968 at the Massachusetts Institute of Technology Civil Engineering Systems Laboratory (19). Its purpose is to assist in the planning and control of projects that can be displayed through a network representation of its activities.

Constraints. PROJECT-I can be based on either actual calendar dates or work day numbers or both. As in most construction operations, there are external scheduling restraints such as holidays and nonworking days. Constraints may be required by the owner such as starting and completion dates or milestone event dates. These and other scheduling decisions by the contractor such as seasonal work slow-downs and long-lead-time item delivery dates can be incorporated into the

program through "constraint" commands before the PROJECT-I schedule is produced.

Network Representations. PROJECT-I is capable of processing three types of network representations; activity-on-node, activity-on-arrow, and event-oriented activity. Some programs are limited to the one which is most commonly used, that of activity-on-arrow. Construction contractors and managers may have their own preference in designing their networks for project planning.

The activity network is first entered into the computer. PROJECT-I uses standard "store" commands and is limited in the number of activities only to a practical network size depending on the computer's limitations. The format of PROJECT-I permits each activity to be assigned an activity code for referencing and selective recall, the estimated activity code for referencing and selective recall, the estimated activity cost value and duration, and the identifying activity number and description. Changes and modifications can be made at any time.

An Example Project. For purposes of demonstrating PROJECT-I's computer output, a portion of a construction project has been developed using hypothetical cost and construction information. The activities selected are those that interface the mechanical construction (i.e.: plumbing, electrical, heating, ventilating, and air conditioning) with its building envelope construction (i.e.: concrete slab, masonry walls, steelwork). The structure, which was completed prior to this writing,

is the Intramural Building at The Pennsylvania State University, University Park campus. Activity-on-arrow network representation is used.

It is not the intent to develop a completed construction project CPM schedule. The activities are selected to show a simplified, yet logical, sequence of events that illustrate some of the output of the computer program, PROJECT-I. (The computer output figures discussed in this chapter can be found in Appendix A). Other activities have been assumed to precede and to follow those identified and displayed in the referenced figures. Although the reader is not required to understand the reasoning for the activity sequences as indicated, a CPM arrow diagram is also shown in Figure 1 for the reader's reference.

<u>Activity Planning Schedule</u>. An Activity Schedule that can be used for planning purposes (Figure 2) lists the activity durations, the computer-calculated start and finish times, and the corresponding float times. A bar chart portraying this same information in graphical, time-scaled form is also available (Figure 3). The annotations shown in the computer output figures will be discussed later.

If constraints such as completion dates or milestone time requirements are included in the schedule, it would be possible to have negative float times. These would then appear on the Activity Schedule. A negative sign would indicate that the time allowed between the project start data and the activity involved is insufficient under the present schedule. The project could not be completed on time, and schedule changes would therefore be necessary. Increasing productivity for the activity, revising activity sequences, revising internal time constraints,

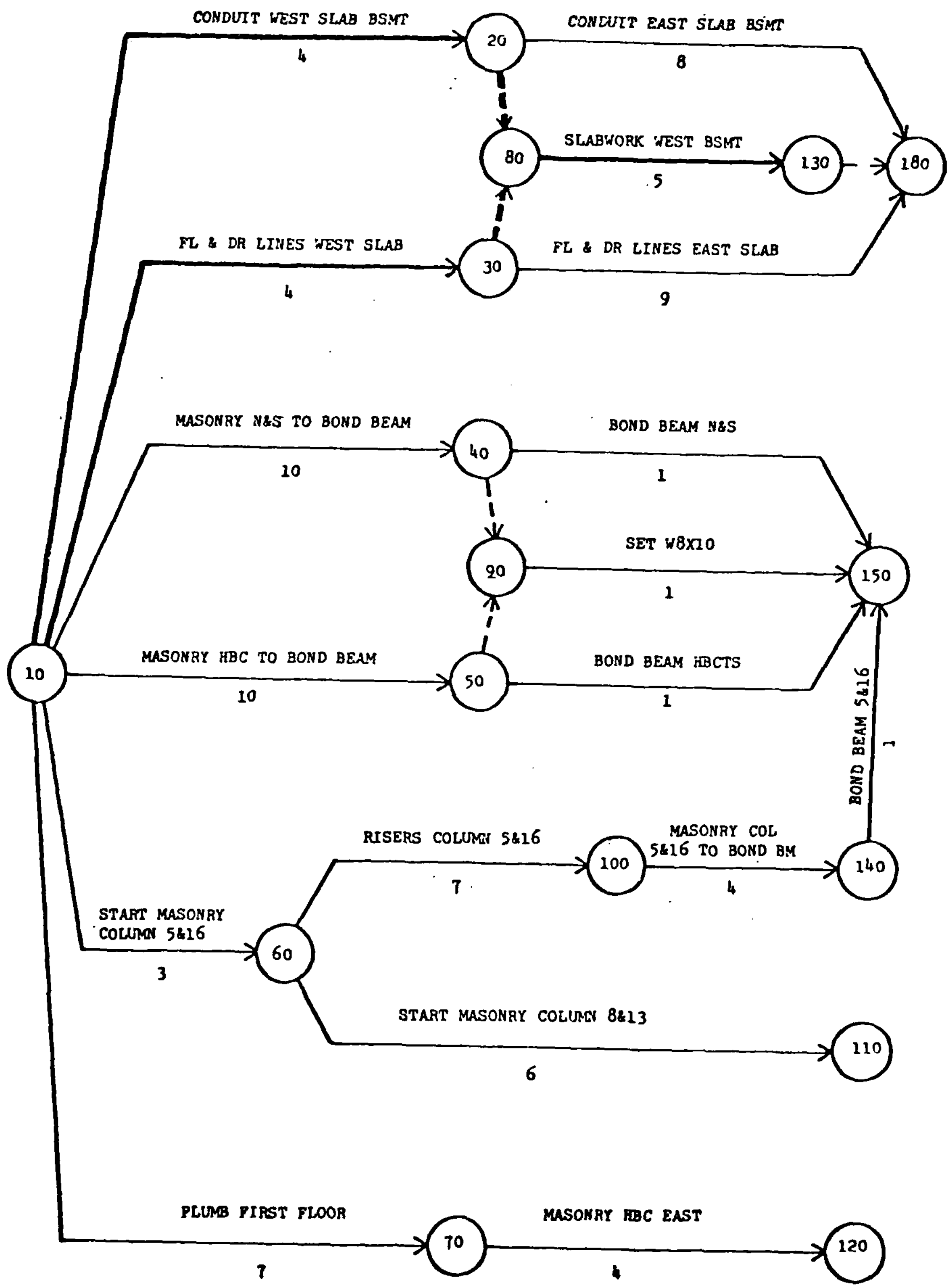

Figure 1. Activity-on-Arrow CPM Network Diagram - Intramural Building, The Pennsylvania State University

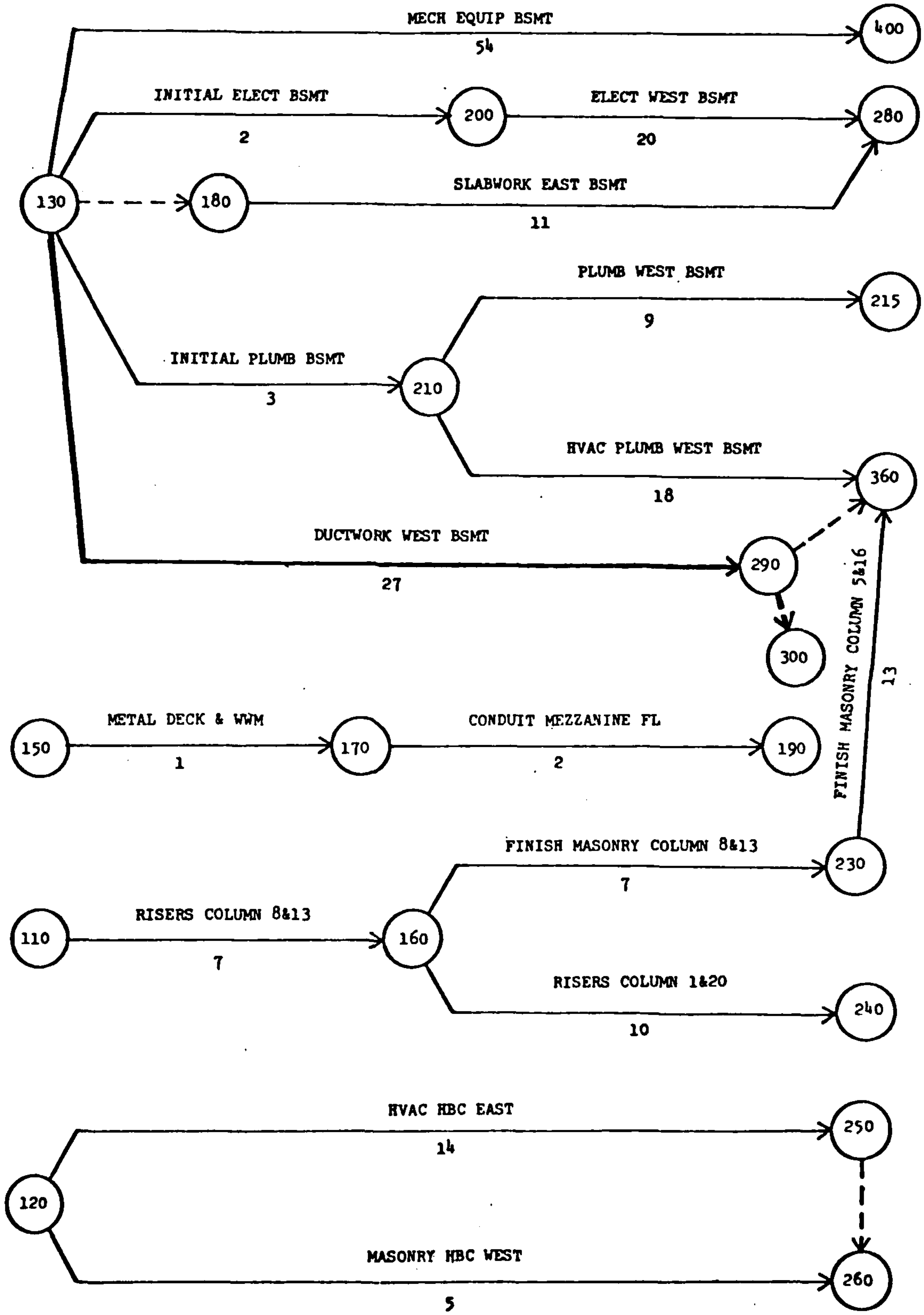

Figure 1. (continued)

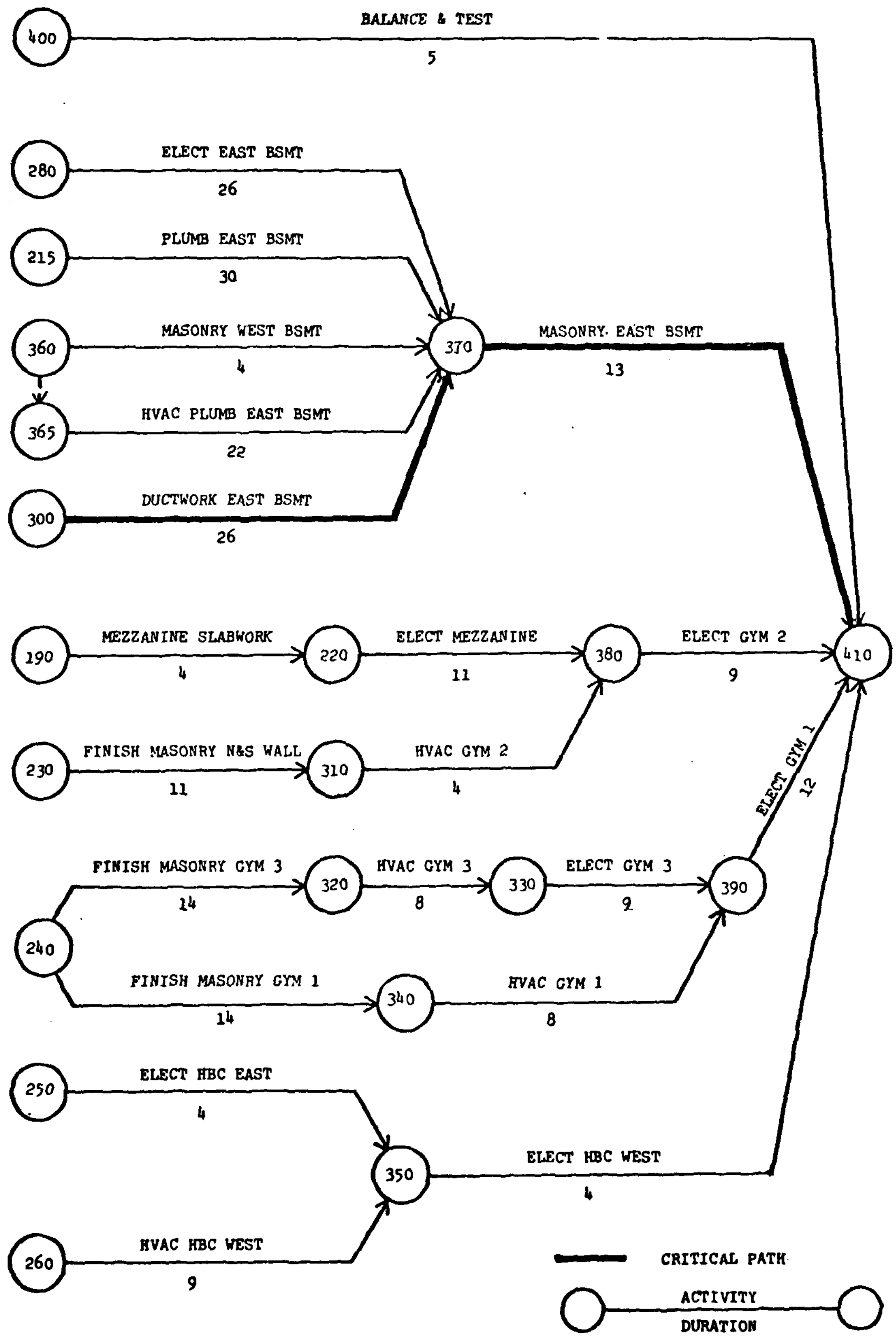

Figure 1. (continued)

*** PSU-ICES: V1N6 ***   PENNSYLVANIA STATE UNIVERSITY - INTEGRATED CIVIL ENGINEERING SYSTEM   *** 12/08/78 PAGE 006 ***

A C T I V I T Y   S C H E D U L E

	ACTIVITY		DESCRIPTION	DURA-TION	EARLY START	LATE START	EARLY FINISH	LATE FINISH	FREE FLOAT	TOTAL FLOAT
C	10	20	CONDUIT WEST SLAB BSMT	4	2OCT78 1	2OCT78 1	5OCT78 4	5OCT78 4	0	0
C	10	30	FL & DR LINES WEST SLAB	4	2OCT78 1	2OCT78 1	5OCT78 4	5OCT78 4	0	0
	10	40	MASONRY N&S TO BOND BEAM	10	2OCT78 1	13OCT78 10	13OCT78 10	26OCT78 19	0	9
	10	50	MASONRY HBC TO BOND BEAM	10	2OCT78 1	13OCT78 10	13OCT78 10	26OCT78 19	0	9
	10	60	START MASONRY COLUMN 5616	3	2OCT78 1	6OCT78 5	4OCT78 3	10OCT78 7	0	4
	10	70	PLUMB FIRST FLOOR	7	2OCT78 1	22NOV78 38	10OCT78 7	4DEC78 44	0	37
	20	180	CONDUIT EAST SLAB BSMT	8	6OCT78 5	25OCT78 18	17OCT78 12	3NOV78 25	1	13
	30	180	FL & DR LINES EAST SLAB	9	6OCT78 5	24OCT78 17	18OCT78 13	3NOV78 25	0	12
	40	150	BOND BEAM N&S	1	16OCT78 11	27OCT78 20	16OCT78 11	27OCT78 20	4	9
	50	150	BOND BEAM HBCTS	1	16OCT78 11	27OCT78 20	16OCT78 11	27OCT78 20	4	9
	60	100	RISERS COLUMN 5616	7	5OCT78 4	12OCT78 9	13OCT78 10	20OCT78 15	0	5
	60	110	START MASONRY COLUMN 8613	6	5OCT78 4	11OCT78 8	12OCT78 9	18OCT78 13	0	4
	70	120	MASONRY HBC EAST	4	11OCT78 8	5DEC78 45	16OCT78 11	8DEC78 48	0	37
C	80	130	SLABWORK WEST BSMT	5	6OCT78 5	6OCT78 5	12OCT78 9	12OCT78 9	0	0
	90	150	SET W8X10	1	16OCT78 11	27OCT78 20	16OCT78 11	27OCT78 20	4	9
	100	140	MASONRY COL 5616 TO BOND BM	4	16OCT78 11	23OCT78 16	19OCT78 14	26OCT78 19	0	5

Figure 2. Activity Schedule

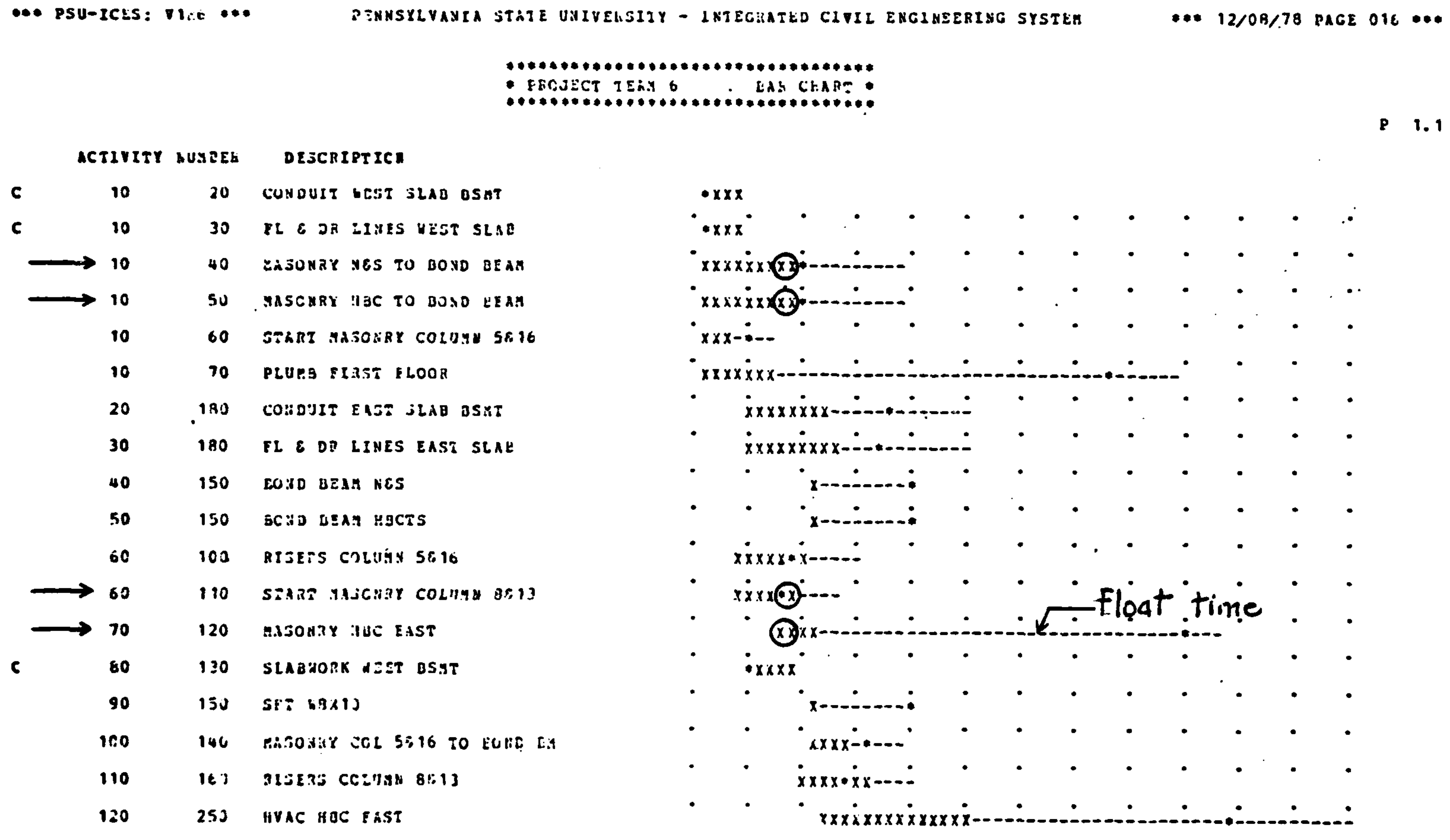

Figure 3. Planning Bar Chart

or obtaining a project extension are some possible solutions available to the construction manager.

There may be situations even when planning a schedule that expediting, as earlier described, is required to determine a schedule that meets a completion deadline or maximizes the profit. With PROJECT-I, the computer can calculate the new scehdule, but the construction manager must determine the cost factors and the activity expediting sequence. (PROJECT-I is not considered to be a very highly automated program in regard to expediting or resource scheduling).

Costs and Resource Planning. PROJECT-I provides a direct relationship of the costs and resources for each activity to aid in the scheduling and planning process. A resource library and cost assignments provide the basis for comparisons and calculations.

The resource library, initially stored in the computer, contains each available resource's description, reference number, category, and unit of measure. Additions, deletions, or modifications of data, can be made at any time. PROJECT-I's programmed resource categories include "labor", "material", "equipment", and "subcontractors", with a separate category for "unspecified" resources.

Costs can be assigned through the resource assignment command, or through the initial activity entry previously mentioned. The resource assignment method is based on cost per unit, while the initial entry method is based on total activity cost. The resource assignment method offers greater flexibility since a change in quantity of units required also changes the activity costs automatically.

Once the library is defined, the required resources, categories, and quantities are assigned to the appropriate activities. The computer analyzes and compares these requirements with the library and performs the necessary calculations for the scheduling and planning reports.

Resource Reports. To utilize this information as a resource planning aid, PROJECT-I makes several resource reports available. These reports enable the project manager to consider problems of resource utilization rates. A multiple listing of any specified number of resources on any time basis requested allows a comparative view of the required resources. Figure 4 is an example of a multiple listing of manpower resources on a daily basis. A single listing of this information is available with options that provide an additional listing of the usage and cost on a cumulative basis. Graphs of the resource information are also available, but are not shown in this thesis.

The resources can be displayed as a list of the resources required for each activity, or as a list of the activities included in each resource category. Figures 5 and 6, respectively, portray examples of these printouts of the manpower application to the demonstration project.

By studying the various resource schedules, the construction manager can quickly determine any resource requirement peaks or valleys which could become "trouble spots." As an example, a resource leveling problem of the demonstration project is analyzed. Figure 4 shows a daily, multiple resource listing of the skilled labor assignments of

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*******************************************
**  RESOURCE USEAGE FOR PROJECT TEAM 6   **
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RESOURCE DESCRIPTIONS

IN COLUMN (1) PLUMBER
IN COLUMN (2) MASON
IN COLUMN (3) ELECTRICIAN
IN COLUMN (4) COMMON LABORER
IN COLUMN (5) SHEETMETAL WORKER
IN COLUMN (6) STEEL WORKER
IN COLUMN (7) CONTROL ENGR

PAGE 1 OF 2

	JOB DAY	COL (1) MANDAYS	COL (2) MANDAYS	COL (3) MANDAYS	COL (4) MANDAYS	COL (5) MANDAYS	COL (6) MANDAYS	COL (7) MANDAYS	COL (
2OCT78	1	6.00	36.37	1.00	0.0	0.0	0.0	0.0	
3OCT78	2	6.00	36.37	1.00	0.0	0.0	0.0	0.0	
4OCT78	3	6.00	36.37	1.00	0.0	0.0	0.0	0.0	
5OCT78	4	3.29	34.70	1.00	0.0	8.29	0.0	0.0	
6OCT78	5	12.17	34.70	1.63	5.40	8.29	0.0	0.0	
9OCT78	6	12.17	34.70	1.63	5.40	8.29	0.0	0.0	
10OCT78	7	12.17	34.70	1.63	5.40	8.29	0.0	0.0	
11OCT78	8	9.17	53.70	1.63	5.40	8.29	0.0	0.0	
12OCT78	9	9.17	53.70	1.63	5.40	8.29	0.0	0.0	
13OCT78	10	13.17	39.70	5.63	0.0	25.43	0.0	0.0	
16OCT78	11	17.14	38.25	5.63	0.0	17.14	2.00	0.0	
17OCT78	12	17.14	29.45	6.52	0.0	23.14	0.0	0.0	
18OCT78	13	24.14	29.45	4.90	0.0	23.14	0.0	0.0	
19OCT78	14	18.25	29.45	4.90	4.82	23.14	0.0	0.0	
20OCT78	15	11.00	17.20	4.90	4.82	23.14	0.0	0.0	
23OCT78	16	11.00	15.20	4.90	4.82	23.14	6.00	0.0	
24OCT78	17	11.90	19.14	6.90	4.82	19.90	0.0	0.0	
25OCT78	18	11.90	19.14	6.90	4.82	19.90	0.0	0.0	
26OCT78	19	11.90	19.14	4.90	14.52	19.90	0.0	0.0	
27OCT78	20	11.90	19.14	4.90	14.82	19.90	0.0	0.0	

Figure 4. Required Manpower Resources

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           RESOURCE ALLOCATION BY ACTIVITIES OF PROJECT 'TEAM 6   '

  10         20CONDUIT WEST SLAB BSMT                     4 DAYS
     3.00    ELECTRICIAN                                          4 MANDAYS

  10         30PI & DR LINES WEST SLAB                    4 DAYS
     1.00    PLUMBER                                             12 MANDAYS

  10         40MASONRY NEG TO BOND BEAM                  10 DAYS
     2.00    MASON                                               96 MANDAYS

  10         50MASONRY NEG TO BOND BEAM                  10 DAYS
     2.00    MASON                                              111 MANDAYS

  10         60START MASONRY COLUMN 5616                  3 DAYS
     2.00    MASON                                               47 MANDAYS

  10         70PLUMB FIRST FLOOR                          7 DAYS
     1.00    PLUMBER                                             21 MANDAYS

  20        180CONDUIT EAST SLAB BSMT                     8 DAYS
     3.00    ELECTRICIAN                                         13 MANDAYS

  30        190PI & DR LINES EAST SLAB                    9 DAYS
     1.00    PLUMBER                                             53 MANDAYS

  40        150BOND BEAM NEG                              1 DAYS
     2.00    MASON                                                3 MANDAYS

  50        150BOND BEAM NBCTS                            1 DAYS
     2.00    MASON                                                2 MANDAYS

  60        100RISERS COLUMN 5616                         7 DAYS
     1.00    PLUMBER                                             23 MANDAYS
     5.00    SHEETMETAL WORKER                                   58 MANDAYS

  60        110START MASONRY COLUMN 9813                  6 DAYS
     2.00    MASON                                               84 MANDAYS
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Figure 5. Resource Allocation by Activities

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RESOURCE ALLOCATION BY RESOURCES ASSIGNED TO PROJECT 'TEAM 6 '

3.00	ELECTRICIAN					
		10	20	CONDUIT WEST SLAB BSMT	4	MANDAYS
		20	180	CONDUIT EAST SLAB BSMT	13	MANDAYS
		130	200	INITIAL ELECT BSMT	4	MANDAYS
		130	400	MECH EQUIP BSMT	108	MANDAYS
		170	190	CONDUIT MEZZANINE FLOOR	4	MANDAYS
		200	280	ELECT WEST BSMT	58	MANDAYS
		220	380	ELECT MEZZANINE	33	MANDAYS
		250	350	ELECT HBC EAST	7	MANDAYS
		280	370	ELECT EAST BSMT	101	MANDAYS
		330	390	ELECT GYM 3	36	MANDAYS
		350	410	ELECT HBC WEST	7	MANDAYS
		380	410	ELECT GYM 2	27	MANDAYS
		390	410	ELECT GYM 1	36	MANDAYS
1.00	PLUMBER					
		10	30	PL & DR LINES WEST SLAB	12	MANDAYS
		10	70	PLUMB FIRST FLOOR	21	MANDAYS
		30	180	PL & DR LINES EAST SLAB	53	MANDAYS
		60	100	RISERS COLUMN 5&16	23	MANDAYS
		100	140	MASONRY COL 5&16 TO BOND BM	29	MANDAYS
		130	210	INITIAL PLUMB BSMT	6	MANDAYS
		130	400	MECH EQUIP BSMT	108	MANDAYS
		160	240	RISERS COLUMN 1&20	9	MANDAYS
		210	215	PLUMB WEST BSMT	72	MANDAYS
		210	360	HVAC PLUMB WEST BSMT	18	MANDAYS
		215	370	PLUMB EAST BSMT	140	MANDAYS
		365	370	HVAC PLUMB EAST BSMT	206	MANDAYS
2.00	MASON					
		10	40	MASONRY HGS TO BOND BEAM	96	MANDAYS
		10	50	MASONRY HBC TO BOND BEAM	111	MANDAYS
		10	60	START MASONRY COLUMN 5&16	47	MANDAYS
		40	150	BOND BEAM HGS	3	MANDAYS
		50	150	BOND BEAM HBCTS	2	MANDAYS
		60	110	START MASONRY COLUMN 8&13	84	MANDAYS
		70	120	MASONRY HBC EAST	76	MANDAYS
		100	140	MASONRY COL 5&16 TO BOND BM	57	MANDAYS

Figure 6. Resource Allocation by Resources

the sample project. As pointed out by the arrows and circles, column two shows that 35 masons are required for the project on day seven. The requirement increases to 54 masons on day eight and decreases to 40 masons on day ten. Obviously the construction manager would not hire 19 more masons for two days and then lay 14 of them off. This does not generate good labor relations and unions generally do not allow this.

The construction manager can utilize his computer output to quickly determine what steps must be taken. By referring to his activity planning bar chart (Figure 3), he can denote which activities require masons on days eight and nine (see annotated activities). If it is not apparent by the activity description if masons are required, it can be quickly confirmed by examining Figure 6, the resource allocation list.

Activity 70 120 (MASONRY HBC EAST), which is scheduled to begin on day eight, is the reason for the increase in the mason requirement. Figures 2 and 3 indicate that float time is available for activity 70 120, thus the activity could be delayed until masons are freed from other activities. The reduction in manpower requirements noted on days twelve and fifteen (see Figure 4) would allow the manpower to be shifted to activity 70 120 at that time. Another solution would be to extend all the concurring activities not on or affecting the critical path by dividing the manpower between the activities. If the other activities were on the critical path and additional manpower was not available, rescheduling or overtime would be required.

Instances where "gaps" or "valleys" occur in the manpower requirements over short periods of time do not create a critical problem. "Filler" activities can be accomplished to maintain productivity and eliminate unnecessary layoffs and rehiring. If the manpower available is excessive, adjustments in resources or activity times can be made, and the computer then calculates the new schedules. The planning cycle continues until a final workable and efficient schedule is derived.

Activity Working Schedule. PROJECT-I continues to aid the construction manager in achieving the successful completion of the construction project after the planning phase. The PROJECT-I activity working schedule (Figure 7) is designed to be used during the actual construction process. Activity progress dates can be manually recorded in the columns provided (see arrows). These field-entered data should then be transferred into the computer on a periodic basis and thus, will be reflected on the subsequent updated working schedule. A comparison check with the manual records will insure that the progress is reported accurately. Since it is also reflected on all other reports, upper level management will then be assured of accurate up-to-date information.

Working Bar Chart. A working bar chart, shown in Figure 8, provides a graphic representation of the activity working schedule. This chart and the working schedule can be based on any activity start dates which are requested. Graphs and activity schedules to be used by field personnel are usually based on early start times.

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A C T I V I T Y W O R K I N G S C H E D U L E

	- D E S C R I P T I O N -		S T A R T		F I N I S H		EST'D DURA-TION
	ACTIVITY NUMBER	CODE NUMBER	SCH'D	REP'D	SCH'D	REP'D	
C	CONDUIT WEST SLAB BSMT 10 20		2OCT78 1		5OCT78 4		4
C	FI & DR LINES WEST SLAB 10 30		2OCT78 1		5OCT78 4		4
	MASONRY NES TO BOND BEAM 10 40		2OCT78 1		13OCT78 10		10
	MASONRY HDC TO BOND BEAM 10 50		2OCT78 1		13OCT78 10		10
	START MASONRY COLUMN 5616 10 60		2OCT78 1		4OCT78 3		3
	PLUMB FIRST FLOOR 10 70		2OCT78 1		10OCT78 7		7
	CONDUIT EAST SLAB BSMT 20 180		6OCT78 5		17OCT78 12		8
	FI & DR LINES EAST SLAB 30 180		6OCT78 5		18OCT78 13		9
	BOND BEAM NES 40 150		16OCT78 11		16OCT78 11		1
	BOND BEAM HDCTS 50 150		16OCT78 11		16OCT78 11		1
	FINISH COLUMN 5616 60 190		5OCT78 4		13OCT78 10		7

Figure 7. Activity Working Schedule

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****
* PROJECT TEAM 6　　BAR CHART *
****

P 1.1

ACTIVITY	NUMBER	DESCRIPTION	
10	20	CONDUIT WEST SLAB BSMT	XXXX
10	30	FL & DR LINES WEST SLAB	XXXX
10	40	MASONRY N&S TO BOND BEAM	XXXXXXXXXX
10	50	MASONRY HBC TO BOND BEAM	XXXXXXXXXX
10	60	START MASONRY COLUMN 5616	XXX
10	70	PLUMB FIRST FLOOR	XXXXXXX
20	180	CONDUIT EAST SLAB BSMT	XXXXXXXX
30	180	FL & DR LINES EAST SLAB	XXXXXXXXX
40	150	BOND BEAM N&S	X
50	150	BOND BEAM HBCIS	X
60	100	FIBERS COLUMN 5616	XXXXXXX
60	110	START MASONRY COLUMN 8611	XXXXXX
70	120	MASONRY HBC EAST	XXXX
60	130	SLABWORK WEST BSMT	XXXXX
90	150	SET 48X10	X
100	140	MASONRY COL 5616 TO BOND BM	XXXX
110	160	FIBERS COLUMN 8613	XXXXXXX
120	250	HVAC HBC EAST	XXXXXXXXXXXXXX
		WORK DAYS	1 . . . 10 . . . 20 . . . 30 . . . 40 . . . 50 . . . 60

Figure 8. Working Bar Chart

Activities shown on the bar chart and activity schedule will then indicate only the early finish times, thus, advocating an early project completion.

Computer reports at the construction field level should be kept to a minimum. The superintendent needs only the pertinent information about the schedule to maintain satisfactory progress, such as the activity working schedule, working bar chart, and a progress summary which includes overdue or late activities.

Progress Summary Reports. PROJECT-I also provides progress and cost analysis through summary and status reports. Progress summary reports consist of the progress analysis of the total project and a cost analysis of the activities included in the report. A sample progress and cost analysis summary is shown in Figure 9.

The progress analysis provides information concerning days worked, duration times, and percentages of planned time and deviations. For the example project, as of 2 November, 24 of the 75 scheduled work days have passed. Based on the reported progress, a revised duration figure of 63 days is now possible. This indicates that the project is 12 days ahead of schedule which is equivalent to the 16 percent deviation. With normal operations, the work should be completed after 30 more work days.

The cost analysis provides total reported and estimated cost figures and any cost deviations. Here Figure 9 indicates that the sample project has total reported costs of $138,891. The estimated costs by day 24 were $144,545 which means the costs are $5,653 or four percent under the estimated costs. Based on the reported

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S U M M A R Y   O F   A C T U A L   P R O G R E S S   A S   O F   2 NOV 1978 (DAY 24)
***********************************************************************************************

PROGRESS ANALYSIS                                                                  DAYS     DATE
-----------------                                                                  --------------

  NUMBER OF DAYS WORKED SINCE PROJECT STARTED                                       24    2NOV78
  SCHEDULED JOB DURATION                                                            75   23JAN79
  REVISED JOB DURATION BASED ON ACTUAL PROGRESS TO DATE                             63    5JAN79
  DEVIATION IN TOTAL JOB DURATION                                                  -12
  = -16.0 PERCENT DEVIATION IN TERMS OF SCHEDULED JOB DURATION
  NUMBER OF DAYS TO GO UNTIL REVISED FINISH DAY                                     39

   32.0 PERCENT OF PLANNED TIME HAS BEEN USED.
   38.1 PERCENT OF PROGRESS ALONG REVISED CRITICAL PATH HAS BEEN ACCOMPLISHED.

COST ANALYSIS                                                            COSTS    OVER    UNDER   PERCENT
-------------                                                            ----------------------------------
  FOR ALL ACTIVITIES INCLUDED IN THE EFFORT
  TOTAL REPORTED COSTS TO DATE                                          136891.
  ESTIMATED COSTS TO DATE                                               144545.
  COST DEVIATION TO DATE                                                                  -5651.     -4.
  EXPECTED COST DEVIATION IN CONSIDERATION OF
  ALL SELECTED ACTIVITIES COMPLETED AND IN PROGRESS                                       -2964.
  ESTIMATED TOTAL PROJECT COSTS                                         392355.

   [illegible] PERCENT OF ESTIMATED TOTAL COSTS HAVE BEEN EXPENDED.
```

Figure 9. Summary of Actual Progress

data, the project completion is expected to cost $2,964 less than the estimated total cost of $392,355.

The percentages of cost and progress can also be compared and analyzed. With 32.0 percent of the planned time used, 38.1 percent of the progress has been accomplished. The difference is equivalent to the 12 day deviation in the schedule. Similarly the cost savings can be further analyzed. While 35.4 percent of the estimated total costs have been used, 38.1 percent of the progress has been accomplished, thus a savings in costs.

From these reports, management can readily determine the economic status of the construction project. If deviations in cost or time are adverse to scheduled progress, the construction manager can examine the activity progress or status reports to determine the individual activity or activities involved.

Progress Status Reports. These reports provide a breakdown of activities and events into several categories; completed activities, activities in progress, and activities overdue to start. Activities in progress are further divided into those that are expected to be completed on schedule and those that are expected to be completed late.

Figure 10 indicates a sample status report of completed activities. The deviation columns (see arrows) of the finish times, durations, and costs indicate which activities were over or under their estimated budgets and time schedules. Excessive lateness can be noted for review to possibly alleviate a similar problem in a recurring activity or on another project.

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CATEGORY 1 COMPLETED ACTIVITIES

- D E S C R I P T I O N -		F I N I S H			D U R A T I O N			C O S T A N A L Y S I S			
ACTIVITY NUMBER	CODE NUMBER	SCH'D	ACTUAL	DEV	ACT EST	DEVIATION DAYS	DEVIATION EC	ACTUAL EST'D	OVER	UNDER	DEV EC
STAFF MASONRY COLUMN 5&16 10	60	4OCT78 3	4OCT78 3	0	3 3	0	0	4200. 4493.		-293.	-7
C FL & DP LINES WEST SLAB 10	30	5OCT78 4	5OCT78 4	0	4 4	0	0	1200. 1248.		-48.	-4
C CONDUIT WEST SLAB BSMT 10	20	5OCT78 4	5OCT78 4	0	4 4	0	0	400. 404.		-4.	-1
PLUMB FIRST FLOOR 10	70	10OCT78 7	10OCT78 7	0	7 7	0	0	1800. 2184.		-384.	-18
START MASONRY COLUMN 8 & 11 60	110	12OCT78 9	12OCT78 9	0	6 6	0	0	7200. 8030.		-830.	-10
C STAIRWORK WEST BSMT 80	130	12OCT78 9	12OCT78 9	0	5 5	0	0	2500. 1965.	535.		27
MASONRY NBS TO BOND BEAM 10	40	13OCT78 10	13OCT78 10	0	10 10	0	0	10500. 9177.	1323.		14
BOND BEAM NBS 40	150	16OCT78 11	16OCT78 11	0	2 1	1	100	300. 286.	14.		5
MASONRY NBS TO BOND BEAM 10	50	13OCT78 10	16OCT78 11	1	11 10	1	10	9600. 10611.		-1011.	-10
INITIAL ELECT BSMT 130	200	16OCT78 11	16OCT78 11	0	3 2	1	50	400. 404.		-4.	-1
FILLERS COLUMN 5&16 60	100	13OCT78 10	17OCT78 12	2	9 7	2	29	8600. 8215.	385.		5

Figure 10. Completed Activities Report - Category 1

Activities expected to finish on or before the planned schedule are listed in the sample report in Figure 11. This information shows the actual start times and expected finish times based on the expected duration. The percentages of completion time and cost are percentages calculated as the elapsed time or cost divided by the total time or cost. For example, activity 130 290 DUCTWORK WEST BSMT, shows 56 percent of the time elapsed while using 52 percent of the estimated costs. The total days elapsed, report day minus start day plus one for inclusion of the report day (24-10+1), equals 15. Elapsed time divided by duration time (15/27) equals 56 percent. Similarly, the actual costs to date divided by the total estimated costs (8400/16,264) equals 52 percent.

The new expected total cost figures are based on continuing the work at the present rate. If 56 percent of the time is represented by $8,400 of the cost, then 100 percent of the project time would be represented by $15,120. The difference between this and the original estimated total cost ($16,264) is indicated as the deviation of $1,144 or seven percent under costs. Although this is only an estimate and will change as the actual progress changes, it can still be used as a guideline by the construction manager in his management decisions. The construction manager will direct his attention to those items which are "over cost" in an attempt to bring them back on schedule.

Figure 12 shows activities in progress that are expected to finish behind schedule. The format and basis for calculations are the same as discussed for Figure 11. The construction manager and the

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CATEGORY 2   ACTIVITIES IN PROGRESS EXPECTED TO FINISH ON OR BEFORE PLANNED SCHEDULE   REPORT DAY 2NOV78 24

- D E S C R I P T I O N - ACTIVITY NUMBER	CODE NUMBER	S T A R T SCH'D	ACTUAL	F I N I S H SCH'D	EXP'D	EXP DUR	PERCENT OF COMPLET TIM	COS	C O S T TO DATE ACTUAL EST'D	TOTAL EXP'D EST'D	A N A L Y S I S EXPECTED DEVIATION OVER	UNDER	PC
HVAC HBC EAST 120 230		17OCT78 12	17OCT78 12	3NOV78 25	3NOV78 25	14	93	85	7200. 7831.	7754. 8433.		-679.	-8
ELECT WEST BSMT 200 280		17OCT78 12	17OCT78 12	13NOV78 31	13NOV78 31	20	65	61	3600. 3815.	5538. 5909.		-331.	-6
C DUCTWORK WEST BSMT 130 290		13OCT78 10	13OCT78 10	20NOV78 36	20NOV78 36	27	56	52	8400. 9036.	15120. 16264.		-1144.	-7
PLCH EQUIP BSMT 130 400		13OCT78 10	13OCT78 10	5JAN79 63	5JAN79 63	54	28	33	11000. 9168.	39600. 33004.	6596.		20

Figure 11. Activities in Progress Report - Category 2

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CATEGORY 3   ACTIVITIES IN PROGRESS EXPECTED TO FINISH   BEHIND   PLANNED SCHEDULE   REPORT DAY 2NOV78 24

- DESCRIPTION - ACTIVITY NUMBER	CODE NUMBER	START SCH'D	START ACTUAL	FINISH SCH'D	FINISH EXP'D	EXP DUR	PERCENT OF COMPLET TIM	PERCENT OF COMPLET COS	COST TO DATE ACTUAL / EST'D	COST TOTAL EXP'D / EST'D	EXPECTED DEVIATION OVER	EXPECTED DEVIATION UNDER	PC
PLUMB WEST ESMT 210 215		18OCT78 13	24OCT78 17	30OCT78 21	3NOV78 25	9	89	75	5600. 6656.	6300. 7489.		-1189.	-16
MEZZANINE SLABWORK 190 220		26OCT78 15	26OCT78 19	31OCT78 22	31OCT78 22	4	150	189	5500. 2912.	5500. 2912.	2588.		89
FINISH MASONRY COLUMN 8613 160 230		24OCT78 17	26OCT78 19	1NOV78 23	3NOV78 25	7	86	74	9500. 10980.	11083. 12810.		-1727.	-13
SLABWORK EAST ESMT 180 270		19OCT78 14	20OCT78 15	2NOV78 24	3NOV78 25	11	91	23	900. 3507.	990. 3858.		-2868.	-74
FILLERS COLUMN 1620 160 240		24OCT78 17	26OCT78 19	6NOV78 26	8NOV78 28	10	60	51	3500. 4115.	5833. 6859.		-1026.	-15
EVAC PLUMB WEST ESMT 210 360		18OCT78 13	20OCT78 15	10NOV78 30	14NOV78 32	18	56	32	600. 1040.	1080. 1872.		-792.	-42

Figure 12. Activities in Progress Report - Category 3

superintendent should both receive this report. When several activities are behind schedule, the computer printout will indicate which activities are more critical and should receive priority in attention. A "C" in front of the activity indicates an activity on the critical path. A "+" indicates an originally non-critical activity that is now critical. A "*" designates that the activity has surpassed its available float time and will extend the project unless changes are made. A project that is in the last class and also "over cost" should, naturally, receive the greatest attention.

Activities that have not begun and are past their scheduled start times are probably the most critical unless excessive float times are available. Once activities begin falling behind schedule, a domino effect can result. Figure 13 is an example of this category of activity report. Scheduled starts and completions are provided with a space (see arrow) for manually posting the expected times as reported from the field.

These late and overdue activity schedules point out problems or potential problem areas as they appear. Manual recording of similar reports will not provide the speed or accuracy to determine this. Thus, "insight" is rapidly gained through computer reports, and problems can receive the required attention before they get "out-of-hand."

When activites are delayed, schedule updates are required to determine the effect on future activities. A new start date which reflects the present time will be required. PROJECT-I does not offer an automatic update of the network schedule, but this can be accomplished through the initial "store" commands used in the planning phase. More complex and larger programs do offer this capability.

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CATEGORY 4 ACTIVITIES OVERDUE TO START

- D E S C R I P T I O N -		S T A R T		F I N I S H		EST'D DURA- TION
ACTIVITY NUMBER	CODE NUMBER	SCH'D	EXP'D	SCH'D	EXP'D	
FIFTH EAST BSMT 215 370		31OCT78 22		13DEC78 51		30
ERECT MEZZANINE 220 380		1NOV78 23		15NOV78 33		11
FINISH MASONRY COLUMN 5616 240 360		2NOV78 24		20NOV78 36		13
FINISH MASONRY N&S WALL 230 310		2NOV78 24		16NOV78 34		11

Figure 13. Activities Overdue Report - Category 4

Predicted Status Report. PROJECT-I offers another basic report that the field and construction managers should find beneficial for future work planning. Although an example is not available, the predicted status report can be very helpful to the construction manager. The computer lists the activities in three categories: those that must be started, those that may be started, and those that must be completed. The reference time for the report can be a given data or a time interval as provided by the construction manager.

When the report is based on a single reference data, all activities except those that may not be started will be listed. To avoid a printout of excessive information, a "look-ahead" interval basis will permit only those activities that fall within the stated interval to be categorized and listed.

Flexibility in Options. PROJECT-I contains multiple output options which can aid the project manager in cost and resource planning and in cost and progress control. Most all reports or schedules can be requested based on a selection of activities desired or a sorting of activities according to the construction manager's needs. This flexibility provides additional management "control by exception" to the required activities and are exceptionally beneficial when the project network consists of hundreds of activities. Much redundant information can also be eliminated and computer printout costs decreased through this flexibility.

Post-Construction Phase

The post-construction phase of a project can be the most important aspect to the success of a project management system. The future of a construction company depends on the degree of importance placed on the post-construction requirements by the company's management. This phase involves the total review and evaluation of the complete project.

Project Results

Everything that goes into a project has a result which can often be measured against a pre-set goal. A comparative analysis of the results and the goals determines the changes required and the steps that must be taken to insure that future construction projects will be equally or more successful. A project with poor results and many problems can offer just as much valuable information as one with a high return of economic gains or with few or no difficulties.

Analysis and Feedback

The information obtained from a project can be stored in a computer data base. This is the data base used in the pre-construction phase, previously discussed, to estimate and plan a project. If the computer was utilized in the construction process, the project information and actual work schedule can be rapidly recalled for review. Actual duration dates, costs, and manpower and equipment usage can be compared to the original project estimations.

The results of the comparison can then be analyzed to provide a basic training tool which will allow learning from experience to take place. Problem areas can be studied and changes made in methods of construction or management procedures to alleviate future recurrences. Cost data and productivity rates can be added to the data base to provide accurate updates for future planning.

In some of the more sophisticated computerized management programs, this updating of the data base is accomplished automatically with each progress report. This provides an immediate feedback for other projects in the planning phases.

The construction cycle is a continuous process from the pre-construction phase through to the post-construction phase and then back to pre-construction phase. Sometimes there is an overlap and sometimes a time gap, but feedback is essential to continue this cycle. The computer provides the communication and management tool to aid its efficient continuation.

Summary and Conclusions

The computer can be a vital tool to the construction manager from the pre-construction to the post-construction phases of a construction project. The complexity of projects has required that greater quantities of information be analyzed, manipulated, and sorted throughout the construction process.

The pre-construction phase offers many opportunities for the computer to aid in the engineering and architectural design. The process

of preparing contract bids involving quantity take-offs and estimates can be more accurately and rapidly accomplished with the computer. The contract documents and drawings can be printed more economically and with greater standardization.

The construction phase consists of the planning, scheduling, and controlling of a project. Through the application of computer programs, the decisions involved in planning and scheduling the construction activities can be made with greater accuracy. A thorough knowledge of the relationships of the many construction work activities is gained through this decision-making process, which in turn aids the construction manager throughout the controlling of the project.

Resource planning is vital to the planning of a schedule. The availability of the men, equipment, and material necessary for a construction project must be considered in the sequencing and scheduling of activities. Manpower leveling and scheduling can be computer aided or totally accomplished through computer applications and programs.

In progress and cost control, the construction manager can request computerized cost and progress reports to meet his management needs. When the actual times and costs are compared to those estimated, the construction manager can determine the status of his project. The computer enables him to quickly pinpoint those activities that are behind schedule and those where the expenses are excessive.

PROJECT-I is an example of a typical computer program used by construction companies to aid in the construction management decision-making. The program is a simplified, basic, network-oriented, construction management tool primarily for planning, scheduling, and controlling a construction project.

The post-construction phase is a vital link in a construction project management system. The emphasis placed on the analysis and feedback of a completed project's results can determine the success of a construction company. The computer is an efficient and rapid management tool that provides the means to accomplish this phase.

CHAPTER IV

AIR FORCE CONSTRUCTION MANAGEMENT

Background

The major portion of the Air Force construction projects are acquired through civilian contracts. Although the contractor is responsible for the project's completion through contractual agreements, the Air Force construction manager is ultimately responsible to coordinate the timely completion and acquisition of the project to meet the user's requirements with emphasis on quality and costs. His direct obligations are to ensure that the project is constructed as specified in the contractual agreements. Basic management practices and knowledge are essential to both the public manager and the private manager. Their ultimate goals are similar, but differences occur in the conditions and limitations of their work.

Financial Accountability

The private construction manager is usually the single focal point of the construction process for his company. He coordinates, directs, and expedites the construction process and the dealings with other organizations involved. He generally has a broad authority and freedom over the decisions affecting his project (8), while his primary attention is directed toward maximizing the profits for his company.

The Air Force construction manager, although responsible for the project, may or may not (as explained later) be the single focal point

in the construction process. He is also subject to a very large, complex, governmental structure whose organization has many lines of control. Project funding approval is essentially at the highest or Congressional level, but this approval may be even further limited as it is reviewed by a system of shared power in the structured organization. The policy governing these decisions is based on public interests and a limitation of resources. With this outlook on funding, the public construction manager, as a representative of the government, must pay vital attention to the accountability of funds rather than to a maximization of profit. It is in this aspect that the computer can provide the means for tighter control and for a more efficient means of tracking the construction progress, which in turn can also provide the required financial accountability.

Rules, Regulations, and Decision-Making

Air Force construction management is based on many rules and regulations which are defined in documents such as Air Force Regulations 88-3 (56), 88-18 (57), and 89-1 (59). These and many others that reference construction management aspects can be obtained from most Air Force Base technical libraries and document procurement sections. A complete listing of all applicable manuals can be found in Air Force Regulation 0-2 (60), which is also available through the same sources. Additional instructions that provide the guidelines for the Air Force construction manager are established to satisfy each project.

The individual decisiveness and risk-taking, associated with the private construction manager, is quite limited or non-existent for the Air Force construction manager (4). Many decisions, especially at the planning and direction level, often involve negotiations and meetings with numerous individuals from various organizations. This has a significant effect on the Air Force manager's abilities and oftentimes requires patience, reasoning, and persuasive tactics to arrive at a decision. For these meetings the Air Force construction manager must utilize concise, clear, and simplified reports concerning the construction project to more efficiently resolve questions and conflicts in the decision-making process. The computer has the capability to provide these reports with the speed and accuracy that will allow the Air Force construction manager more time to prepare meaningful and concise presentations to benefit all the organizations involved.

Coordination

Air Force construction can vary from runway repair to housing developments to space shuttle launch facilities. The coordination and knowledge required for the different types of projects varies tremendously. The Air Force construction manager must familiarize himself with all facets of each project. He is responsible for coordinating the requirements of the representatives from the contracting agency, the contractors, the designers, the tenant command who will be utilizing the facility or project, and the host command who is acquiring the physical structure.

With the magnitude and diversified agency interest in most projects, it is absolutely necessary to have an organized means for coordination and communication. These agencies must be kept informed on an accurate, timely, and continuing basis of the status of the project, the existing and potential problems, and the status of change orders in order to efficiently and effectively manage the project and control cost growth.

Construction Management System

Unlike the private construction manager, the Air Force construction manager's responsibilities extend beyond the normal construction project operations. It appears that the Air Force construction manager must be a specialist in many areas or have an exceptional ability to be able to comprehend and master the total aspect of his responsibilities. Since he controls the project primarily through his surveillance responsibilities[1], he needs a management system that can accurately and quickly enable the pertinent surveillance reports and information to be sorted and meaningfully presented.

A primary management tool available to aid in these duties and also be the focal center of a good management system is the computer. Although the Air Force construction manager does use the computer in this management system to some extent, this writer feels there should

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[1]Major Peter LoPresti, Chief, Military Construction Division, Air Force Regional Civil Engineer/Central Region, in a telephone interview, November 22, 1978.

be increased computer utilization and necessary and mandatory improvements in its application.

Computers and Air Force Construction Management

This section discusses some reasons why knowledge of computer benefits and their applications to Air Force construction management are important. Possible applications of computers are examined as they apply to three levels of construction management organizations. The extent of each application is based on the scope and size of the project. Examples of actual instances are given where an Air Force construction manager's computer background and knowledge did result in the procurement and use of the computer, thus saving time and effort.

It appears that if more Air Force construction managers understood the advantages available through the application of computers in construction management, there would be greater emphasis placed on its utilization. This writer feels that there are two major reasons for the Air Force construction manager to know more about computers. One reason is to make him capable of analyzing and understanding the contractor's CPM reports and knowledgeable to provide direction on the content and format of desired reports. The second reasons is to provide the Air Force construction manager the background for possible direct use of computers either on a time sharing basis or through use of the local Air Force Base's computer system, when it is available.

Computer Application

Computer application in Air Force construction management has not received the emphasis that it has in other Air Force operations.

The Air Force has been a major user of computers in the standard usage areas such as logistics, inventory control, payroll and finance, and general record keeping. It has also been a leader of computer applications in areas such as weapons systems, missile and satellite tracking. scientific research in materials, weather observation, and communications in our national defense. In fact, the strategic defense of our nation is extremely dependent on a multiple, integrated layer of computer systems.

Recent research using computers is being conducted by the Air Force Civil Engineers in a study of environmental control, air pollution, and energy conservation. Systems are also presently being installed in selected Air Force facilities that provide total energy monitoring and control through a computerized system.[2] These examples are merely indications of the total application of computers in the Air Force.

Contracting Agent's Input. The Air Force construction management program does not share this acceptance and application of the computer. It appears that the major reason for this has been the fact that the COE and NAFAC, acting as the contracting agent, do make a provision for requiring computerized network scheduling by the contractor "if" it is felt that the government can benefit by its use.

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[2] Captain Charles D. Sprick, Resident Air Force Regional Civil Engineer, Lackland Air Force Base, Texas, in a telephone interview, November 22, 1978.

This "if" is related to the complexity of the project as determined by the number and interrelation of activities, volume and nature of work, geographical location, and time requirements for completion. Relating this to a dollar volume, the COE considers a construction project exceeding $300,000 as "usually sufficiently complex to benefit from management by network analysis system," while construction projects over $500,000 can be accomplished "more economically and more efficiently" if computers are used for the mathematical analysis in the network printouts (6).

With the Army and the Navy providing the contracting services and establishing the criteria for computerized network scheduling, it is essential to question whether there is any actual requirement that increased computer knowledge and background be made available to Air Force construction managers. *Is there a need for increased training and education in computer applications for the Air Force construction manager and is there a need for the advanced use of computers in Air Force construction management?*

Air Force Phase IV. One aspect that must be considered before these questions and statements can be discussed is that the Air Force has accepted bids (December 1978) for the largest, single acquisition of computers. This is considered Phase IV of the Air Force's computerized system. The purpose is to extend automated data processing support to the base-level users by the year 2000 (27), which would appear to indicate that by the year 2000 the Air Force construction manager could possibly have access to the computer on a regular basis. Obviously, this does not relieve the present situation, but it does

show that there is concern and some action is being taken. It is up to the individual construction managers and supervisors to take advantage of whatever situations they can.

Computer Application Consensus

Based on personal experience, telephone interviews, and personal interviews with Air Force construction managers who are or have been working "first-hand" in the Air Force construction management field, a consensus concerning computers is: the situations where computers can be applied as a management tool do exist in the Air Force construction field, the interest and basic intuition are present, and the junior managers or young engineers out of college have had the computer orientation, but have not experienced practical application situations.

It is also felt that the opportunity to use a computer is currently non-existent, especially at the base level because computers are either not physically available or computer time is not permitted for use by the Air Force construction manager. Another drawback to the lack of computer application is that a number of senior construction management personnel have not had the opportunity to receive training similar to that of the young engineers. Thus, they tend to use traditional manual methods and are reluctant to accept or seek the aid of the computer in their work.

As with most consensus and viewpoints, there are exceptions. In this case, the exceptions only strengthen the position advocating increased knowledge and application of computers. These exceptions

demonstrate the possibilities that exist if the desire, knowledge, and need are present. Some of these occurrences are discussed as they pertain to the various levels of Air Force construction management.

Organizational Levels

The management organization in the civilian contractual arrangements on Air Force construction projects can have several levels depending on the size and requirements of the project. Figure 14 shows the simplified management lines of communication used for small projects. The Air Force construction manager acts as the agent and coordinator of the entire project with direct communication with the contractor.

Figure 15 shows the inclusion of the contracting agent as a separate level, with the Air Force construction manager overseeing the agent and coordinating the overall project requirements. In this case, the Air Force construction manager is a step removed from direct contact with the contractor, but remains the focal point for other coordinating activities.

Figure 16 shows a variation that exists on certain projects where a large degree of technical coordination of the user's activities and equipment is required. Such is the case in the multi-million dollar expansion and renovation of the Wilford Hall Medical Center at Lackland Air Force Base, Texas. A separate construction management division is necessary to coordinate the user's requirements. It is noted that Figures 14, 15, and 16 represent very simplified charts of

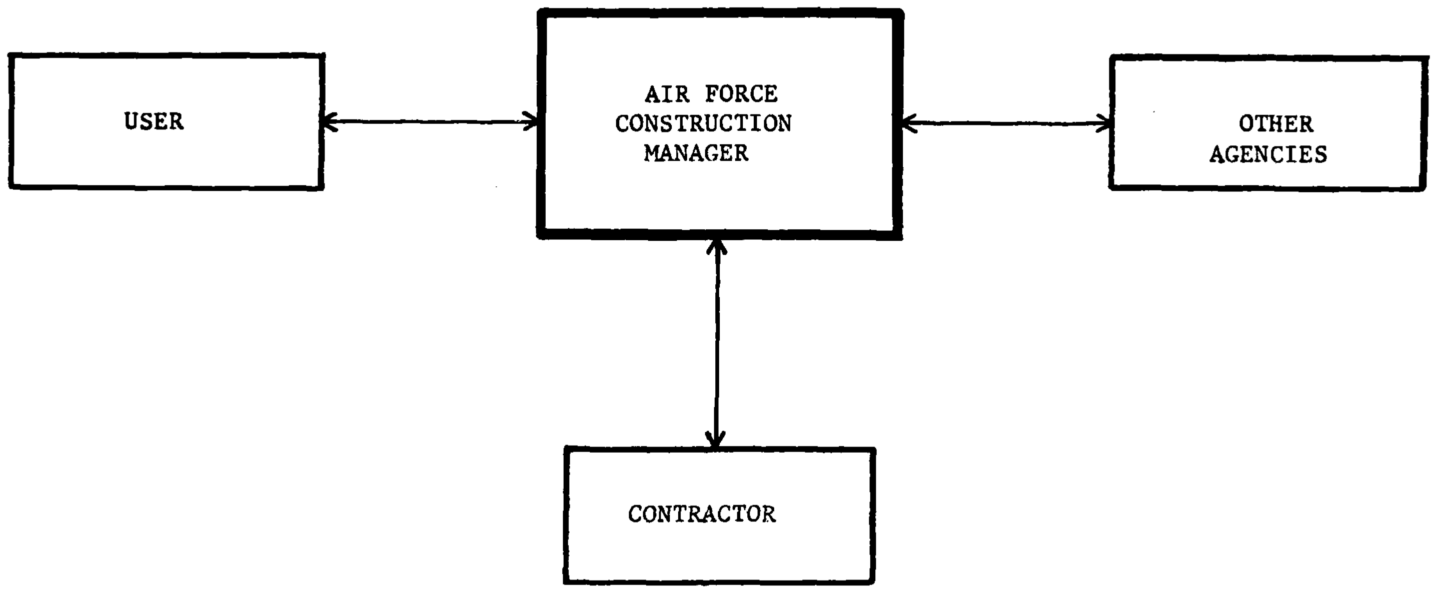

Figure 14. Simplified Project Organization Chart - Small Construction Project

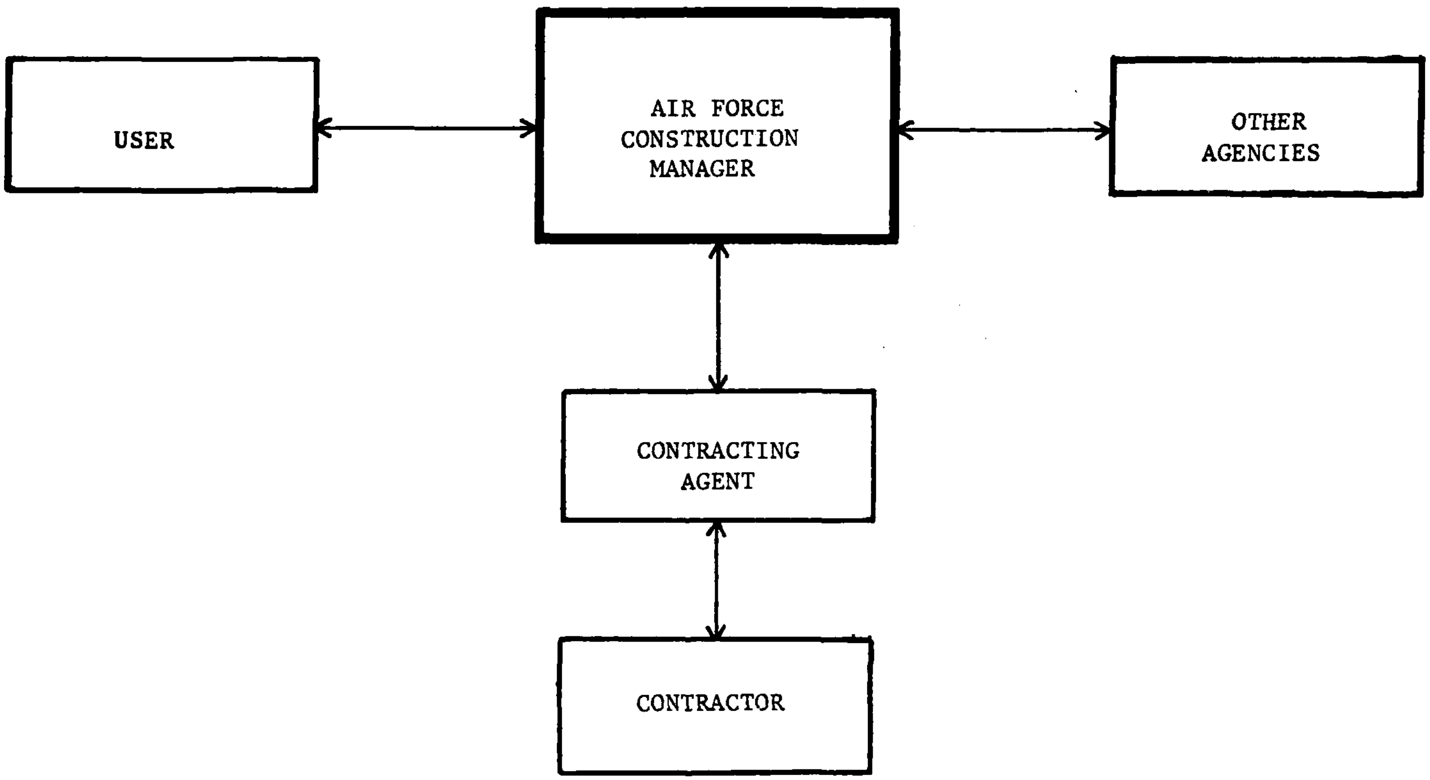

Figure 15. Simplified Project Organization Chart - Large Construction Project

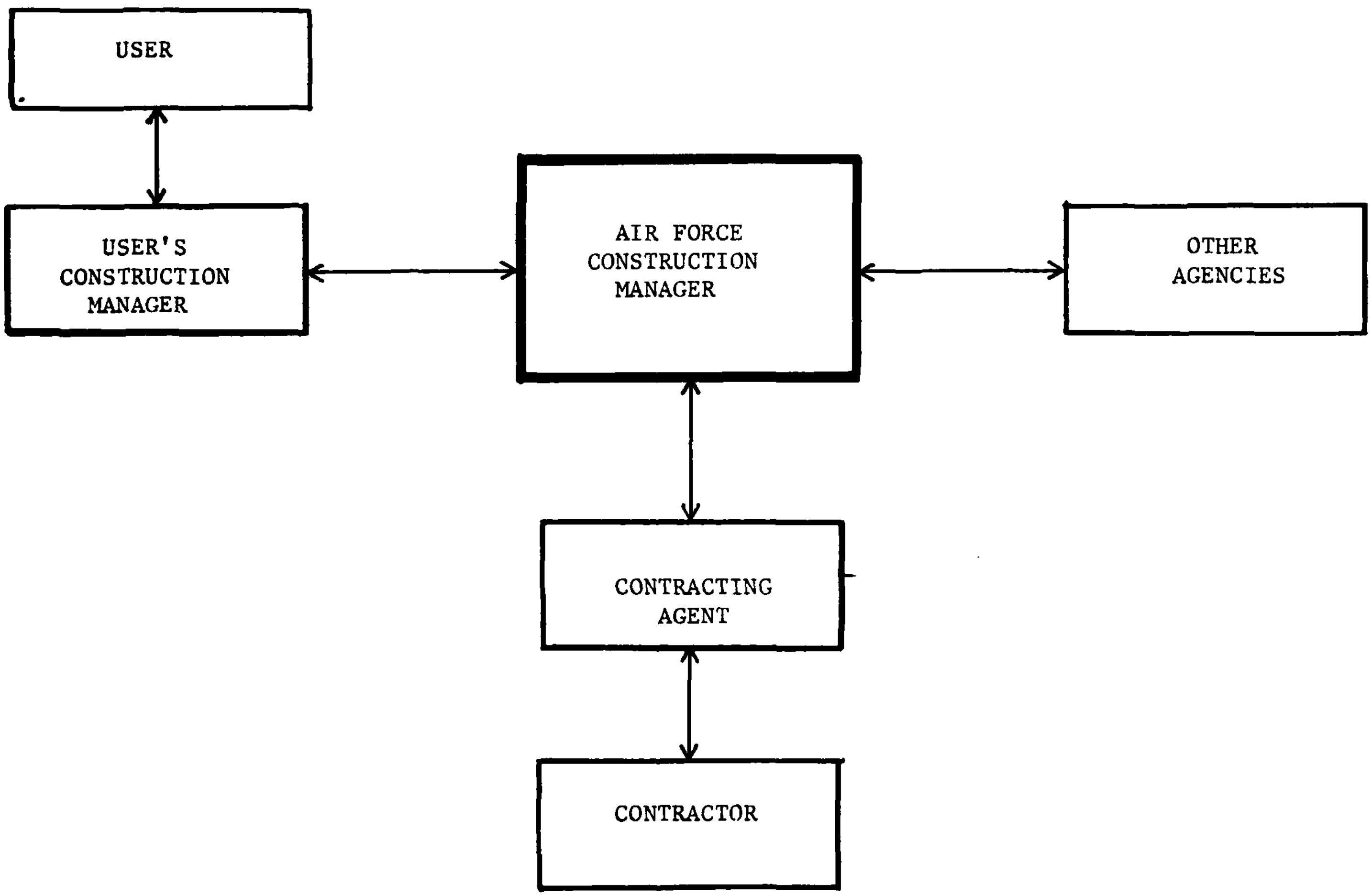

Figure 16. Simplified Project Organization Chart - Large, Complex Construction Project

AD-A091 030 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH F/G 9/2
COMPUTER APPLICATIONS FOR AIR FORCE CONSTRUCTION MANAGEMENT.(U)
AUG 79 D V HENRICHSEN
UNCLASSIFIED AFIT-CI-79-198T NL

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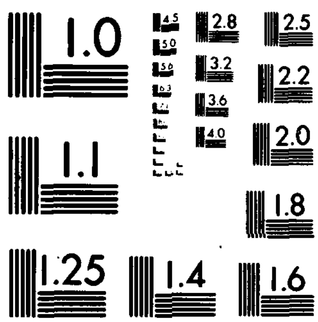

MICROCOPY RESOLUTION TEST CHART

field level management. There are several other regional and district control levels that are typical of government organization which are not shown.

The type of organization required on a project is largely dependent on its size, dollar volume, and complexity. The simplest form is usually that used at the base-level for small construction projects such as small housing developments, runway construction, or recreation facilities. The other two types might be used for large projects such as large housing developments, administrative complexes, hospital expansions, or space shuttle system facilities.

Small Construction Projects

On small projects, the Air Force construction manager is the direct line of communication and focal point of the entire project (see Figure 14). Because the project is small and not complex, he must also perform the additional functions of the contracting agent. This requires a more intimate contact with the construction process and the contractors.

Contractor/Construction Manager Relationship. Although the actual planning and scheduling of the construction process is accomplished by the contractor, the Air Force construction manager must aid the contractor by determining and coordinating the Air Force requirements. He can also specify the type of plan and schedules that would aid in accomplishing these requirements. Using these schedules, he can coordinate requirements such as disruptions to traffic flow, elimination of parking or access routes, and occupancy of transition moves with the related agencies.

During the actual construction, the Air Force construction manager maintains direct contact at the field management level to insure that the final product will be in accordance with the contract provisions. His total responsibilities remain as previously discussed.

The conscientious and aspiring Air Force construction manager will endeavor to be familiar with every aspect of the project under his direction. By keeping "on top" of his project, he cannot only guide it toward its satisfactory completion, but can also possibly make additional time-saving and valuable cost-effective inputs. His knowledge of the project and managerial effectiveness will depend on the information available to him and the personal inspections made by him.

Progress Reports and Computers. On the smaller projects, the contractor may be using traditional manual methods of progress reporting and updating. The Air Force construction manager should be, therefore, thoroughly familiar with such management tools as the Gantt chart, precedence schedule, and CPM network diagrams. These traditional methods of progress control also provide a basis for computer program applications.

The construction contract should state when and if a computerized network schedule is required. The Air Force construction manager must determine this by analyzing his project's complexity together with the benefits obtained by utilizing the computer. To accomplish this, he must first be aware of the benefits and capabilities of the computer in construction programs.

It should be noted that it is possible to "over-manage" a project. Too many reports and too much redundant information can have a detrimental effect on management comprehension and decision-making. A problem can also occur when a computerized network schedule is required and the contractor does not utilize the computer for other than a monthly report or the contractor does not have experience in computer applications. This defeats the purpose of the computer, causes added expense and duplication of work, and can result in insufficient or incorrect information.

Construction Manager's Influence. The Air Force construction manager can have a significant influence on how the computer is utilized on these smaller projects. His direction to the contractor can set the standard he expects for the project. If the contractor realizes that the Air Force construction manager does understand how the computer can aid in controlling the project, better communication between them is possible.

Some items, such as work requiring a power outage on the Air Force Base, may be critical to other Air Force operations, but not to the contractor. If the Air Force construction manager has the ability to read and understand the computer outputs, without first requiring a detailed briefing of each, he can quickly review the reports and determine the appropriate action required.

Since computer programs are capable of consolidating reports and information in almost any format or in any sorting order desired, the Air Force construction manager can, therefore, request that specific information and formats be included on his weekly or monthly reports.

The result is a simplification of the progress review procedures, thereby allowing him to more professionally make the projections and decisions which are necessary to remain on schedule and within budget. The resultant savings in time also allow other coordination and management responsibilities to receive greater attention. The key to this success lies in the Air Force construction manager's knowledge of computer capabilities and ability to properly interpret the reports which are produced.

Example of a Construction Manager's Initiative. The computer can be a valuable management tool and accounting system for other small construction management responsibilities as well. On projects that are designed and constructed by Air Force personnel (such as base housing and building renovations, roadwork repair, and small additions), the computer could be beneficial, if it were available for use by the base-level civil engineer in construction management situations. This availability has occurred in only a few situations and then only as a result of the personal efforts and persuasion by the individuals who had the background or attained the knowledge of the computer's benefits and capabilities.

For example, at the Air Force Academy's engineering and construction division, the increase in the cost of construction maintenance and repair brought about a requirement to increase the control of these items. The manual methods of calculating and recording the work breakdown and costs of each unit were based on "rules of thumb" and were previously considered "adequate." It was determined that a more sophisticated and accurate accounting system was required to control and reduce costs.

Application of the computer to this problem appeared to be the solution. The senior manager in charge of the division had not had any previous opportunity to learn of computer benefits and capabilities, but instead of insisting on another manual solution to the problem, he began his own computer "training period." After an extensive time period of asking questions, reading books and articles, and taking courses on computers and their applications, he and another construction manager set up a computerized system for better control.

The problem was not completely solved with computer knowledge alone. Most Air Force bases either do not have computer services available or do not allow computer time to be used except for already "canned" programs. Fortunately, the Academy did have a computer dedicated to its academic construction and research work. With a little persuasion, sufficient computer time was allocated to incorporate the accounting and cost program which was based on a converted version of an inventory control program.[3]

Upon implementation of the program, another problem became apparent which actually reflected the basic computer problem: lack of knowledge of computer applications. The workmen were not reporting their time accurately or fully, and needed to be educated to the fact that in order for the information which was to be obtained from a computer to be of any value, the input information must be accurate and up-to-date.

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[3]Mr. Lawrence Clark, Chief, Technical Review Branch, Engineering and Construction, Civil Engineering, Air Force Academy, Colorado, in a telephone interview, November 22, 1978.

Once these problems were solved, the computer was able to keep an accurate record of the work accomplished, along with its associated cost, on each construction project or housing unit. Fast recall and the capability to quickly retrieve only required information now aids in the planning and scheduling which is required on the recurring building maintenance, while excessive work costs are sorted and identified for management action.

This example emphasizes one of the few situations which the writer has found where a senior Air Force construction manager saw a need for improvement, had the desire and initiative to learn about computers on his own, and then put his knowledge to use in applying the computer to solve his problem. It is evident that the knowledge of computer benefits and applications can lead to better construction management.

Other Computer Applications. Other areas of possible computer applications exist in the design and engineering divisions of the Air Force. These areas are generally at the base-level where computer time has not been allocated to the engineer. The solution of many preconstruction problems in technical work areas of the structural, hydraulic, and surveying functions can be greatly expedited by many of the already existing commercial programs. Much time spent in laboring over tedious calculations can be eliminated, thus resulting in greater efficiency.

Younger, Inexperienced Construction Managers. Today's younger officers and civilian personnel usually enter the Air Force construction management field at the small construction or base level. Having

obtained some form of computer orientation through their education, they are more receptive to the use of computers, recognize its advantages, and have the intuition to apply the computer to their work. What they lack is the practical application and experience with a computer and the availability of the computer[4,5,6]. Given the opportunity to have access to the computer, they offer great potential to the Air Force construction division at the small project level and eventually at the large project level.

Large Construction Projects

On large projects, the Air Force construction manager is a step removed from the contractor at the field level (see Figure 15). The organization of this level, as mentioned earlier, can vary depending on the complexity involved. Construction management personnel are sometimes required in both overall project management control and in the user's management coordination (see Figure 16).

Construction Manager's Responsibilities. The Air Force construction manager of the large projects, as in the small projects, is responsible to coordinate the requirements of the user and the other agencies, as well as to maintain project surveillance and control. He is not

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[4]Ibid.

[5]Mr. Clinton C. Boyd, Director of Development, Wilford Hall Medical Center, Lackland Air Force Base, Texas, in a telephone interview, November 20, 1978.

[6]Captain Charles D. Sprick, Resident Air Force Regional Civil Engineer, Lackland Air Force Base, Texas, in a telephone interview, November 22, 1978.

usually involved at the field level to the degree of the construction manager of the small projects because the contracting agent (COE or NAFAC) assumes these responsibilities. The agent also provides the Air Force construction manager with the computerized progress reports.

Computer Applications. As with the contractor's computer reports, to effectively read and understand the contracting agent's reports also requires the Air Force construction manager to possess some computer background knowledge or receive detailed briefings. The major use of the reports is for progress tracking and payment authorization. Modifications and changes can also be given closer attention if they are accurately tracked through use of the computer.

The most critical aspect in monitoring progress in large construction projects involves the "look-ahead" schedules.[7] These can be requested through computerized programs for various future periods: thirty day, sixty day, six month, etc. Of extreme importance is the ordering and delivery of the special equipment procured by the Air Force which requires long-lead times. The "look-ahead" schedules can show explicitly the time schedule in which the work activities are to begin or are to be completed, so timely procurement of these special items can be coordinated. The computer can provide the required information rapidly and in a quite visible format, whereas a manual system would require tedious chartmaking and updating.

[7]Major Peter LoPresti, Chief, Military Construction Division, Air Force Regional Civil Engineer/Central Region, in a telephone interview, November 22, 1978.

Computer Application Example - Wilford Hall Medical Center. On projects with multiple complexities, a separate management division coordinates the user's requirements with the Air Force construction manager. The Wilford Hall Medical Center project, for example, involved the construction of the hospital addition, the renovation of the original section, and the construction of a total energy plant. Complications occurred since the hospital was required to remain in operation during both the construction and renovation phases. This required a continual moving process as new sections became operational. Medical equipment and power plant items had critical delivery times due to their technical nature. Manpower, trucks, and other moving equipment had to be scheduled in advance to accomplish the required timely critical moves. To keep track of the total requirements proved to be far beyond the capabilities of a manual system of charts, graphs, and records.

The construction coordinator for the hospital initially performed a thorough research and analysis of the project requirements to validate the need for a sophisticated management support system. He then reviewed available commercial computer programs and compared their characteristics with his requirements. A system was selected and the request for funding and computer support from higher headquarters was approved.[8]

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[8]Lieutenant Colonel Green, Computer Staff Officer, Wilford Hall Medical Center, Lackland Air Force Base, Texas, in a telephone interview, November 20, 1978.

The computer program selected has provided the tracking capability for the user to coordinate the occupancy requirements. Unlike the contractor's program which deals with the construction process, the main emphasis in this program used by the Air Force construction manager was placed on the tracking of the actual progress and forecasting the crucial activities that affect the hospital's transition and equipment installation. The control data was based on the contractor's actual start and finish times, while the corresponding activities were selected for their relationship to the hospital's needs. The computer calculated the critical path and "flagged" trouble spots and critical activities in progress reports for quick review and management-by-exception.

A major problem was avoided, for instance, when a particular aspect of the construction process began to slip its schedule. An analysis of its total expected delay was made and a simulated "slip date" was placed in the computer program. Through the computer program's ability to simulate the future schedule, all anticipated "upsets" and changes were determined. Management was then able to compensate for these, thus avoiding later costly changes and adverse conditions. The computer in this instance was considered to be a "lifesaver."[9]

In this example, the individual responsible for obtaining and utilizing a computerized management system had the required background

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[9]Mr. Clinton C. Boyd, Director of Development, Wilford Hall Medical Center, Lackland Air Force Base, Texas, in a telephone interview, November 20, 1978.

in computer operations. Therefore, when he requested funding for his computer package, he had the knowledge of the benefits of the computer and could readily justify his request. Although nothing was written in his job description requiring an education in computers, he was certain that he was selected for the position on the basis of his computer education.

Computer Application Example - Space Transportation System. Another example that further emphasizes the possibilities of computer applications occurred in the pre-construction phase of the Space Transportation System (STS). A requirement was made from a department head for a management system to track and portray the developments of the various design phases of the STS program. The individual given this responsibility had an educational background in computers. Knowing the computer's advantages in displaying and calculating this type of information, he naturally began to seek a computerized management system.

The construction manager had another basic advantage in this situation. Because his section was part of a larger division, a minicomputer system was already physically available and a computerized management system was already being used by another office. The construction manager determined that the capabilities of the program could be incorporated for his use, made his formal request for funding, and received a separate file in the computer program. As in the previous example, the computer knowledge that provided the basis needed to verify the request for computer usage was the key to its being approved and funded.

The next obstacle involved the actual operation of the computer. Again relying on his educational background, the manager learned to run the program through on-the-job training from the software representative and since then has made his own inputs, changes, updates, and format selection for the desired reports and schedules.[10]

One disadvantage in this particular situation is that until another individual can be taught to operate the minicomputer, the construction manager will have to make his own inputs. Also, if he is transferred to another assignment prior to anyone else learning the system, or if his replacement does not have the computer training, his efforts and management continuity and effectiveness will be lost. Therefore, the requirement is further established for more Air Force construction managers to obtain the necessary computer knowledge and background.

Unlike the previous example, however, this construction manager did not feel he was selected for his position based on his computer background. Thus, his case emphasizes the fact that there are positions and opportunities where the Air Force can definitely benefit from the construction manager's knowledge of computer applications.

Conclusion from Examples. From the first example there was an indication that the Air Force does realize the computer's importance and does, perhaps, attempt to utilize the computer knowledge of

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[10] Lieutenant Colonel Raymond E. Rodgers, Space Transportation System Program Coordinator, Space Transportation System Branch, Engineering Construction Division, Space and Missile System Office, Los Angeles Air Force Station, California, in a personal interview, July 20, 1978.

certain construction managers. The second example showed that the opportunity to apply computer knowledge also exists in other, non-selected positions. It is concluded that if more personnel were trained in the computer field of construction management, a greater utilization of computers and their benefits would be realized.

It is felt by this writer that the Air Force, therefore, should place greater emphasis on computer training and authorize more construction managers to receive formal education and training in computer applications to Air Force construction management. As a follow-up, the Air Force's Civil Engineering assignment section should then, even if already attempting this to some degree, be more selective in making assignments. Thus, they could attempt to insure that positions with greater potential for computer application would be filled with those individuals who have received the appropriate computer education.

Automated Military Construction Progress Report System

Background. The Automated Military Construction Progress Reporting System (AMPRS) is a standard computer progress reporting system used by the Army Corps of Engineers as part of the total COE Management Information System (COEMIS) for controlling purposes. It was developed by the U.S. Army Construction Engineering Research Laboratory as a result of a comprehensive analysis during 1970 of construction progress reporting systems used by local contractors in various Army Districts. Its purpose is to provide standardized progress information to the various Army construction divisions and users such as the Air Force construction managers. More accurate and

timely information in less time and with less costs provides management with an effective tool to aid in their planning and decision-making responsibilities (15).

<u>Complexity</u>. AMPRS is a detailed and extensive system. Five individual user's manuals are required by the various personnel using the program. The use of each depends on their personal responsibilities in its operation. The COE also uses the program for management control over its many divisions and widespread construction system. The Air Force construction managers use only a small portion of its total capability. Without any previous knowledge or background of computers, the Air Force construction manager would require detailed study and training to become proficient in its use.

<u>Benefits</u>. AMPRS provides computer benefits to construction progress reporting. Manual methods of report preparation involved much time consumed in typing and an overlap in information gathering. With information gathered one time and stored in a data base, it can be recalled and printed with greatly increased speed. Typing and computational errors are also eliminated. This results in a savings of time, and hence a savings of money.

Each project and report also has its own identifiers and activity data. The identifiers indicate who is responsible for the work, where it is performed, what the work is, who the contractor is, and a contract number. The activity data includes actual, estimated, and obligated costs, actual or estimated design or construction dates, percentages of completeness of costs, explanatory remarks, and contract

modifications. This information is especially essential in reporting to higher headquarters and to other users such as the Air Force. The Air Force construction manager, in turn, uses this information in his reports and to accomplish his management responsibilities.

Data Base. The data base forms the heart of AMPRS. The elements of every project under the COE control that could be used for project and construction management progress reporting are included. These are organized and identified through a detailed coding system that provides project interrelations, yet maintains an overall interface with the COEMIS system. Each project has numerous stored, common data elements that are used in the various reports.

Output Report Format. Standard output reports are available automatically. The format of these reports was based on an analysis of all reports previously used in the different divisional areas in order to insure that all important points would be included. Other formats and sortings can be requested as required in order to make different comparisons and summaries of the project information which is available. This would involve a change in programming similar to those mentioned in the previous chapter. Thus, standardization is achieved, yet flexibility in information output or reporting is maintained.

Input Data. System input of the project data is usually accomplished at an Army organizational level called the District. This involves coding, keypunching, and loading the field information and other data into the data base. As an indication of the possible

complexity involved, a system analyst/programmer, a data processing equipment operator, and two individuals from both engineering and construction are required to perform this task. The Air Force construction manager does not become involved in this procedure, therefore, a detailed knowledge of the program language and commands is not required.

Output Data and Reports. System output consists of two types of information: system control and reports for management. The system control information is used by technical support personnel. There are sixteen standard reports and variations of these reports that are designed to satisfy routine reporting requirements. Since this thesis is primarily concerned with the particular management information reports which are distributed to the Air Force construction managers for information and project control purposes, they will be the only ones which are discussed below.

1. The Air Force Status of Design Funds Worksheet, for instance, supplies a listing of the design fund status in the format specified by the Air Force. With this knowledge, projects exceeding the scheduled limitations will be noted for management action.
2. A District Design Report-Air Force Project provides in-depth information about Air Force projects in the design phase. The project design manager can monitor this detailed information to aid him in his overall management decision-making process.

3. A District Construction Report provides a similar indepth analysis about projects in the construction phase. This information is used by project managers who are immediately responsible for the construction work.
4. Many modifications and changes are usually associated with large Air Force projects. The Contract Modifications and Pending Items Report lists the projects and the data associated with any modifications of the project.
5. The District Exception Reports are vital reports for management-by-exception. They are actually a series of six reports for design, construction, or a combination of both. The reports identify project items having over-runs or underruns of key funds, construction periods, or dates, but are listed only if they occur during the reporting cycle.
6. The Using Service Design Status Report provides a monthly report for the user. It lists each project in the design phase and provides information such as design start dates, percent completed, review dates, project advertising dates, and bid opening and award dates.

7. The Using Service Construction Status Report is the construction phase version of the previous report. It contains the approved funding amount, the contract bid amount, actual and scheduled completion percentages, start dates, completion dates, and scheduled occupancy dates.

Additional Management Capabilities. Additional schedules and network diagrams are supplied as required through the COEMIS from another program called Resource Allocation/Project Management System. These network plots show the events and activities of the project based on a computer-calculated, critical path method analysis. The network model serves as the master plan which allows the construction manager to visualize the total integration of the project. Differing strategies and decisions can be simulated and the results studied before actual application, thus avoiding possible delays or economical losses.

AMPRS has the capability of preparing additional managerial reports as requested by the Air Force construction manager. To know what additional information might better aid him, the Air Force construction manager must first understand AMPRS. This will require knowledge and actual experience that cannot be gained in an overview of this type of system. Such an exposure is beyond the limits of this thesis.

Application Level. Unlike ICES PROJECT-I discussed in Chapter III, AMPRS is oriented to a higher level of management review. The

Air Force construction manager does not receive or have the need for all of the information which is available. Some information which is provided is the basis for cost control and the higher level decisions, while other information is used to assist him in his daily coordination and monitoring responsibilities.

This higher level or apparent remoteness to the actual construction process can be explained by reemphasizing the Air Force construction manager's relationship to the construction project. In projects using AMPRS, the Air Force construction manager is a step removed from the actual project supervision. The information required to perform his responsibilities in the larger, more complex projects is not the same as that used by the contractors in their daily planning, scheduling, and controlling of a project.

The Air Force Construction Manager and AMPRS. It is apparent that AMPRS has many capabilities and can produce many reports. Since each project differs in the reports it requires, the Air Force construction manager must be able to determine which reports will aid him in his work. It has been indicated that at times some reports are left to "gather dust" and are considered unnecessary.[11]

It is quite probable that AMPRS, when using only standardized reports, does include redundant or unnecessary information. It has been noted, however, that AMPRS has the capability to prepare

[11] Captain Charles D. Sprick, Resident Air Force Regional Civil Engineer, Lackland Air Force Base, Texas, in a telephone interview, November 22, 1978.

additional managerial reports as requested by the Air Force construction manager. It is felt by this writer, therefore, that Air Force construction managers with increased knowledge of computer capabilities must help to alleviate any unnecessary or redundant information. Utilizing his knowledge of the computer program and its capabilities, the Air Force construction manager can decide which reports will best aid him in his management duties and insist on receiving only pertinent information.

Summary and Conclusions

Air Force construction projects are usually constructed by private construction contractors under the control of the Air Force construction manager. His responsibilities include construction surveillance, fund management, change request approval, cost minimization, and project expediting. In addition, a major responsibility involves the coordination of the user's requirements with those of the contractor and other tenant agencies to meet the construction schedule.

Computer applications to aid in Air Force construction management have not received the emphasis which has been felt in other areas of the Air Force. Interviews with Air Force construction managers in the field determined that the opportunity for computer applications does exist and the basic intuition and intellect are available to utilize computers. Drawbacks to this application include the lack of computer accessibility, tendency to utilize traditional methods, lack of knowledge, training, and practical experience with computers, and the differing roles involved in the management organizations of the Air Force construction projects.

Air Force construction projects can be placed in basically three categories: small projects, large projects, and large, complex projects. On small projects the Air Force construction manager works directly with the contractor on a daily basis and has the best opportunity to determine the needs and extent of computer application. On either type of large project, the Army or Navy construction divisions usually act as the contracting agent, thus, the Air Force construction manager is a step removed from the field operations level. The contracting agent directly controls the contractor and also provides the computer reports to the Air Force construction manager. It is the responsibility of the construction manager to determine if the content and format of the computer reports provide the necessary information to effectively and efficiently aid him in his management duties.

A program used by the Army Corps of Engineers (COE) to supply these reports is the Automated Military Construction Progress Reporting System (AMPRS). The COE utilize this report as part of a larger central information system to control several projects in a district region. Several standard reports are available, while other formats and sorting can be requested in order to make different comparisons and summaries of project information available. Before the Air Force construction manager can analyze these reports and make sound management judgements, he must have the knowledge of computer applications.

Several examples of situations in the Air Force construction field have portrayed some opportunities to obtain computer programs and utilize computers. The key to computer applications in these

situations was a sound background of computers in two cases, while a third case resulted from determination and personal training and study.

It is concluded from these examples and the consensus of the previously discussed interviews that greater opportunities to utilize computers in the Air Force construction industry do exist. The primary ingredient lacking is the initial knowledge and awareness of computer capabilities and applications. To alleviate this problem and receive the benefits of the computer in the construction field, the Air Force must place greater emphasis on computer training and education, together with making the computers and computer programs more available to the Air Force construction manager.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The application of computers in the construction industry can provide many benefits to the construction manager as he attempts to meet his responsibilities. Though initially it was widely rejected, the computer has recently become more readily acceptable to construction managers. One area that has not achieved this extensive computer usage to any significant degree is Air Force construction management.

Considered in this thesis were three basic areas of computer knowledge: computer development, computer application to private construction management, and computer application to Air Force construction management. These were areas that, when analyzed, provided the basis for an introductory document to aid the Air Force construction manager in the accomplishment of his duties.

An overview of the developments of the computer illustrated the various factors and attitudes that were present when the computer was first developed. Many of the problems related to the acceptance and application of the computer have also affected the Air Force construction program. These problems and the developments that made computers more acceptable were presented to make the Air Force construction manager aware of the extensive technology and advancements which have improved the computer. Training programs which indicate

some methods in which the computer can be used as an additional educational tool as well as to gain practical management simulated experience were discussed.

The application of computers in the pre-construction, construction, and post-construction phases of a project was analyzed and discussed with regard to the areas of application, options available with various programs, and the benefits derived. Actual computer output for a sample demonstration project was analyzed and portrayed using a basic construction management computer program, ICES PROJECT-I.

Air Force construction management was analyzed on the basis of pamphlets and programs supplied by various military agencies. In order to obtain "first-hand" knowledge of computer applications at the various levels of management, interviews were made of Air Force construction managers who are working, or have worked at these levels. Experiences and consensus opinion concerning the availability and application of computers at these levels provided the basis for the analysis. An overview of a military computer program provided a measure which indicated the difference between the private and public computer programs, as a reflection of their management roles.

The purpose of this study was to provide, in an introductory document, an overview of the benefits of computer applications as applied to the Air Force construction management field. The approach taken in the study was directed at providing a starting point from which the Air Force construction manager could turn to gain knowledge of the application of computers to Air Force construction management.

Conclusions and Recommendations

The computer's capabilities and capacities have greatly increased through advanced technology. With their reduction in cost, they have become widely accessible for utilization as a management tool.

The greater complexity and costs of today's construction projects require sophisticated management systems. Construction management systems utilizing the computer have been developed that provide time saving and economical benefits for construction management. Therefore, it is recommedned that the Air Force place greater emphasis on the application of computers in their construction management program to realize these benefits.

From the analysis and study of the computer's development and its application to private and public construction management, the following conclusions and recommendations to aid in achieving the computer's benefits are made:

1. The Air Force construction manager's utilization of computers is usually directly related to his knowledge and understanding of their applicability and capability. The Air Force should authorize more construction managers to receive formal education and training in computer applications.
2. A computer's potential cannot be achieved without the support and backing of the higher levels of management. Although the

younger Air Force engineers and construction managers have usually received an orientation to computer applications and capabilities through their college educations, their knowledge and ability to apply computers and the benefits to be gained by computer application cannot be achieved without the support from these higher levels of management. Concurrence and recognition of this fact must be greatly emphasized and endorsed from the "top", so the young managers' initiative and intuition can be utilized to the best interest of the Air Force.

3. The allocation of computer time to Air Force construction operations at the Air Force base-level is not readily available. It is felt that when the Air Force's Phase IV computerized system (the purpose of which is to extend automated data processing to the base-level users) is adopted, Air Force construction managers at this level should be allocated computer time. Until that time, however, emphasis should be placed on obtaining greater utilization of computer time-sharing capabilities available to Air Force construction managers.

4. The opportunity to gain practical experience in construction management without costly errors is

available through computerized games. If the Air Force construction manager is able to gain access to the computer, games of this type should be included as part of his on-the-job training program.

5. On small construction projects, the Air Force construction manager is in the position to use his computer knowledge to aid in his duties and to obtain the benefits of the computer. Through his direct relationship with the contractor, he can control the type and amount of information desired. His direction to the contractor should set the standard of computer utilization he expects for the project. The Air Force construction manager should, therefore, make it a contractual requirement that the contractor provide the Air Force computerized, modified and designed for Air Force construction management purposes, as determined by the Air Force construction manager.

6. When computers are available through other departments, or there is a potential for computer utilization such as on large, complex construction projects, Air Force construction managers have been able to obtain computer time by validating and substantiating their

request. If these managers are selected for their assignments based on their background, greater utilization of computers and their benefits can be realized. Therefore, the Air Force should make this a primary concern in its assignment selection criteria.

7. The contracting agent for the Air Force, whether it is the COE or NAFAC, does use computer programs to provide construction management reports. Some of the information provided is redundant, while some is unusable to the Air Force construction manager because he does not have the knowledge to understand it. The Air Force construction manager should request a thorough briefing from the agency providing these reports as to the contents and meaning of each report. He can then decide what is pertinent and can aid the contracting agent to utilize the full capability of the computer program to tailor redundant reports to meet the Air Force construction manager's needs.

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Rodgers, Major Raymond E., Space Transportation System Program Coordinator, Space Transportation System Branch, Engineering Construction Division, Space and Missile System Office, Los Angeles Air Force Station, California, personal interview by David V. Henrichsen, July 20, 1978.

Sprick, Captain Charles D., Resident Air Force Regional Civil Engineer, Lackland Air Force Base, Texas, telephone interview by David V. Henrichsen, November 22, 1978.

APPENDIX

Software Package Information

Almost unlimited variations exist in computer software packages for construction management purposes. Besides the many programs commercially available, construction and construction management companies have developed their own programs or tailored other programs to meet their organizational needs. Program capabilities vary from basic construction project scheduling and control programs for a single project to comprehensive programs with many options and the capability to handle several projects simultaneously.

PROJECT-I (discussed in Chapter III) is considered one of the basic computer programs. An advanced program called PROJECT/2 offers network plotting, CPM scheduling, progress control, cost processing, resource allocation and constraining, and multiproject features. The degree of program capability is directly related to the cost of the program. Whereas PROJECT-I is relatively inexpensive, PROJECT/2 can be purchased for approximately $25,000. Many programs can be purchased outright or rented on a monthly basis. The cost usually includes several days of training and follow-up consultation.

To obtain information for this thesis regarding construction management computer programs, the writer attempted to contact software centers, construction companies, construction management firms, and computer sharing bureaus. Of the thirty-five organizations contacted, only six responded; three provided pertinent information, while the

remainder provided general information or order forms to purchase additional information. It is felt that an Air Force construction manager in a position to request and authorize the purchase of computer programs for an actual construction project would have received a better response.

As an aid to the Air Force construction manager in search of available programs, the following directory listing of software package sources is provided. This is only a partial listing since, as noted above, there are hundreds of software centers and other sources available. Additional sources are also continually forming or available through the expansion of computer services. The companies listed do provide software packages for construction management purposes in the planning, scheduling, accounting, and controlling of a construction project. Their costs and capabilities vary from one program to another.

As a continuation research project, the interested reader could expand this listing. Research criteria could include additional sources, cost and capability comparisons of programs, equipment requirements, and program names and functions. Additional listings and information on software packages could possibly be obtained from the computer departments of major universities, construction companies who offer their programs to the public, and computer library centers where available.

American Software & Computer Company
550 Pharr Road, Suite 630
Atlanta, GA 30305
(404) 261-4381

Andrew Sipos Associates
104 East 10th Street
New York, NY 10016
(212) 986-6560

Atlantic Software, Inc.
Lafayette Building, Suite 910
5th & Chestnut Streets
Philadelphia, Pa 19101
(215) 922-7500

Babcock & Wilcox Company
20 S. Van Buren Avenue
Barberton, Oh 44204
(216) 753-4511

Bristol Information Systems
P. O. Box 2133
Fall River, Ma 02722
(617) 679-1051

CDC
Software Documents
4201 N. Lexington Avenue
St. Paul, Mn 55112
*

CEPA
P. O. Box 1532
Rockville, Md 20850
(301) 762-6803

CESL
Department of Civil Engineering
Massachusetts Institute of Technology
Cambridge, Ma 02139
*

Computer Applications Corporation
413 Kellogg
Ames, Ia 50010
(515) 232-8181

Computing and Information Sciences Corporation
810 Thompson Bldg
Tulsa, Ok 74103
(918) 583-5791

Construction Information Systems
Box 484
Mill Valley, Ca 94941
(415) 332-5073

* Telephone information unknown

Construction Management System
P. O. Box 90
Haddonfield, NJ 08033
(609) 429-4030

COSMIC
University of Georgia
112 Barrow Hall
Athens, Ga 30602
(404) 542-3265

Cybernet Publications
Applications Services
Minneapolis, Mn 55440
*

Digital Equipment Corporation
146 Main Street
Maynard, Ma 01754
(617) 897-5111

EDP Design Consultants, Inc
140 Weldon Parkway, Suite 4
St Louis, Mo 63043
(314) 432-5797

General Services Administration
18 & F Street NW
Washington, DC 20405
*

Honeywell Informations Systems
200 Smith Street
Waltham, Ma 02154
(617) 890-8400

IBM Corporation
General Systems Division
5775 Glenridge Drive
Atlanta, Ga 30301
(404) 256-7000

IBM Corporation
1133 Westchester Avenue
White Plains, NY 10604
(914) 696-1900

* Telephone information unknown

Information Sciences, Inc
125 Dupont Drive
Providence, RI 02901
(401) 278-5900

International Systems, Inc
890 Valley Forge Plaza
King of Prussia, Pa 19406
(215) 265-1550

Itel Corporation
10801 National Blvd
Los Angeles, Ca   90064
(213) 475-8627

Keith and Associates, Inc
2655 Villa Creek Drive
Suite 125
Dallas, Tx 75229
(214) 620-1860

Martin Marietta Data Systems
300 E. Joppa Road
Towson, Md 21204
(301) 321-5744

McDonnell Douglas Automation Company
Box 516
St Louis, Mo 63166
*

MSP Inc
594 Marrett Road
Lexington, Ma 02173
(617) 861-6130

Multiple Acceys Computer Group
Toronto Data Center
885 Don Mills Road
Don Mills, Ontario M3C 1W2
(416) 443-3904

NCR Corporation
5225 Springboro Pike
West Carrolton, Oh 43449
(514) 449-5241

* Telephone information unknown

Nichols and Company, Inc
1900 Avenue of the Stars
Los Angeles, Ca 90067
(213) 556-2757

Olivetti Corp of America
500 Park Avenue
New York, NY 10022
(212) 371-5500

Peter F. Loftus Corporation
Chamber of Commerce Bldg
Pittsburgh, Pa 15219
(412) 391-2280

Peter J. Hogg
216 Miller Avenue
Mill Valley, Ca 94941
*

Program Control Corporation
Hathaway Bldg, Suite 408-B
7120 Hayvenhurst Avenue
Van Nuys, Ca 91406
(213) 782-2900

Project Software & Development, Inc
14 Story Street
Cambridge, Ma 02138
(617) 661-1444

Quality Data Products, Inc
P. O. Box 76065
Atlanta, Ga 30328
(404) 434-6160

Sperry Univac Division
Sperry Rand Corporation
P. O. Box 500
Blue Bell, Pa 19422
(215) 542-4011

Sysnet Company
322 W. 52nd Street
Suite 311
New York, NY 10019
(212) 868-3330

* Telephone information unknown

Systonetics, Inc
600 N. Euclid Street
Anaheim, Ca 92801
(714) 778-1600

Technical Economics, Inc
573 the Alameda
Berkeley, Ca 94707
(415) 525-7774